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THE FUTURE USE OF DSCS AND COMMERCIAL SATELLITES IN THE U.S. NAVY

by

Robert J. Zoppa

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Thesis Advisor: Dan C. Boger

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All three satellite systems currently have a place in the Navy's SATCOM architecture. This thesis focuses on the advantages and disadvantages that the DSCS satellite network offers the Navy and recommends using DSCS for low capacity protected circuits and high capacity unprotected service in the future. Additionally, a recommendation is made for a future high capacity DSCS follow-on satellite. This thesis also addresses the advantages and disadvantages that INMARSAT and INTELSAT offer the Navy and recommends that these systems be used as surge communication mediums in the future.

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The Future Use of DSCS and Commercial Satellites
in the U.S. Navy

by

Robert J. Zoppa
Captain, United States Army
B.S., United States Military Academy, 1987

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Author: Robert J. Zoppa

Robert J. Zoppa

Approved by: Dan C Boger

Dan C. Boger, Thesis Advisor

Carl R. Jones

Carl R. Jones, Second Reader

R Panholzer

Rudolf Panholzer, Chairman
Department of Space Systems Operations Academic Group

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I. INTRODUCTION

A. BACKGROUND

Prior to 1990, the Navy's use of the Defense Satellite Communications System (DSCS) Super High Frequency (SHF) satellite communications (SATCOM) system was limited to six flagships and a limited number of Surveillance Towed Array Sensor System (SURTASS) ships. In the spring of 1990, the Chief of Naval Operations (CNO) determined that the Navy needed to introduce additional SHF SATCOM capabilities and utilize an integrated SATCOM architecture consisting of Ultra High Frequency (UHF), SHF, Extremely High Frequency (EHF), and commercial systems. SHF SATCOM would allow the Navy to communicate with other services and Allied countries on the modern battlefield.

In the winter of 1991, Operation DESERT STORM created an urgent need to introduce additional SHF SATCOM terminals into the fleet. Without SHF terminals, the Navy could not obtain current, up-to-date Air Tasking Orders (ATOs) from the Joint Force Air Component Commander (JFACC). This urgent need caused the Navy to quickly put together a SHF SATCOM program with little planning and limited funding.

Today DSCS SHF SATCOM terminals are embedded on ships throughout the fleet, but are encountering several problems.

First, the Navy is limited to low data rates on the DSCS satellite constellation. The highest data rate currently allocated to the Navy on selected DSCS satellites is 512 kilobits per second (kbps). (Naval Space Command, 1994, p. 2-3) This data rate must be shared by several ships in one ocean region. Second, as the defense budget continues to shrink, there is limited congressional support for expensive DSCS satellites and terminals. (U.S. GAO, 1993, p. 2) Third, the EHF MILSTAR program is well underway and will be capable of handling limited anti-jam (AJ) requirements once reserved for the DSCS network. Finally, commercial satellite systems are now available that deliver high data rates to small mobile users (over 1.544 Mbps) at a fraction of the cost of the DSCS network.

B. OBJECTIVE

The objective of this thesis is to conduct a detailed examination of the United States Navy's current use of the DSCS III and commercial satellite systems and to provide insight for future use. The analysis of commercial satellite systems will be limited to the International Maritime Satellite (INMARSAT) and International Telecommunications Satellite (INTELSAT) systems.

C. ORGANIZATION

This thesis is organized into eight chapters. Chapter I is a brief introduction. Chapter II describes the DSCS III satellite syctem in detail. This chapter describes the history behind the DSCS III satellite constellation and focuses on communication capabilities. Chapter II details the communication payloads found on DSCS III satellites which will be referred to throughout the thesis. Chapter III describes the Navy's current use of the DSCS III satellite system. This chapter provides the reader with a brief history of the satellite system in the Navy, highlights current terminals, circuits, and satellite transponder usage, and points out advantages and disadvantages that the DSCS III system offers the Navy. Chapter IV provides insights into future Navy requirements for the DSCS III system. Chapter V describes the INMARSAT and INTELSAT satellite systems in detail. This chapter describes the history behind each satellite constellation and focuses on communication capabilities. Chapter V also details communication payloads on INMARSAT and INTELSAT. Chapter VI describes the Navy's current use of the INMARSAT and INTELSAT satellite systems. This chapter provides the reader with a brief history of the use of INMARSAT and INTELSAT satellite systems by the Navy, highlights current terminals, circuits, and satellite transponder usage, and points out advantages and disadvantages each system offers the Navy. Chapter VII provides insights

into future Navy requirements for these commercial satellite systems. The final chapter provides conclusions and recommendations on how the U.S. Navy should best utilize the DSCS III, INMARSAT, and INTELSAT communications systems in the near future. The final chapter also highlights recommendations for DSCS follow-on satellites.

II. DSCS III SATELLITE CONSTELLATION

A. HISTORY

The Defense Satellite Communications System (DSCS) consists of a series of geostationary satellites originally designed to provide reliable satellite communications service to the United States Military and to Allied Forces throughout the world. The DSCS was initially planned for long-distance, point-to-point communications between fixed installations with large diameter (approximately 60 feet) antennas. The DSCS satellite constellation has evolved through three phases of satellite design since its inception in 1960.

The Initial Defense Communication Satellite Program (IDCSP) satellites provided limited operational capability from 1967 to 1975. The second set of DSCS satellites (DSCS II) was more advanced and contained a command subsystem, attitude control and stationkeeping capability, and multiple communication channels with multiple access capability. DSCS II satellites began operation in 1971 and some continue to provide limited capabilities even today. The most current set of DSCS satellites (DSCS III) provides higher capacity, improved jam resistance, and increased connectivity, compared to the DSCS II satellites. The first DSCS III satellite was placed in operation in 1983.

The current DSCS III communications system was planned in the late 1970s. It was specifically designed for strategic users who desired a high degree of anti-jam capability combined with physical survivability. (Finney, 1990, p. 1) The current DSCS III constellation consists of five primary satellites in synchronous orbit covering the East and West Atlantic, East and West Pacific, and Indian Oceans. Three older DSCS III satellites are kept in orbit as reserves. In addition, there are six DSCS III satellites in storage awaiting future launch. Although the initial plan for the DSCS was to support large fixed terminals, the increasing need for large amounts of information on the tactical battlefield has expanded the DSCS mission. Today, DSCS III satellites support large fixed terminals as well as small, mobile terminals.

B. COMMUNICATION CAPABILITIES

The DSCS III satellites contain two communication subsystems. The primary subsystem consists of a six-channel transponder capable of receiving Super High Frequency (SHF) signals from 7900 to 8400 MHz, and transmitting SHF signals from 7250 to 7750 MHz. The SHF signals used by DSCS III satellites are contained within the X-band portion of the frequency spectrum. The secondary communications subsystem is the Air Force Satellite Communications (AFSATCOM) single channel transponder (SCT). The SCT is capable of using the

same receive and transmit SHF frequencies as the SHF transponder as well as receiving Ultra High Frequency (UHF) signals from 300 to 400 MHz and transmitting UHF signals from 225 to 260 MHz. The UHF signals used by DSCS III satellites are contained within the S-band portion of the frequency spectrum. The primary function of the SCT is to provide secure and reliable dissemination of the Emergency Action Messages (EAM) and Single Integrated Operational Plan (SIOP) communications from World Wide Command Post ground stations and aircraft to the force elements. (DCA, 1984, p. 4-34)

1. Payload Configuration

The primary communications payload on the DSCS III contains eight antennas that can be connected in several ways to the six-channel limited bandwidth transponder. Each channel has its own limiter, mixer, and transmitter and can be tailored to support specific types of user requirements. Communication performance is enhanced by allocating the independent channels according to operational needs. For example, channels with similar modulation techniques or terminals with similar antenna gain-to-noise temperature (G/T) ratios would be grouped together. Figure 1 illustrates the variable payload configuration on each of the most recent DSCS III satellites.

The six-channel transponder does not process or demodulate signals, therefore any type of modulation or

multiple access may be used. Multiple access techniques include: spread spectrum multiple access (SSMA) and carrier detect multiple access (CDMA) to support electronic counter-countermeasures (ECCM) operations, frequency division multiple access (FDMA), and time division multiple access (TDMA). (SPAWAR, 1993, p. 3-7)

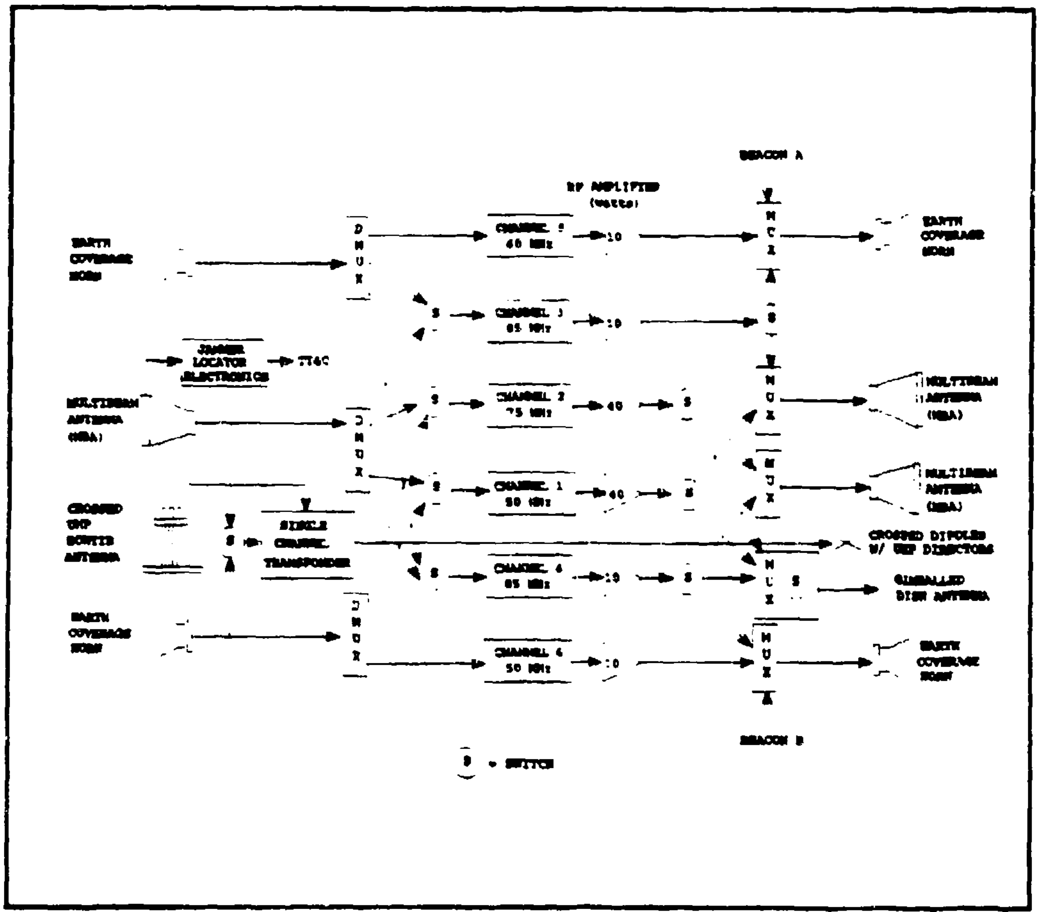

Figure 1. DSCS III Payload Configuration (DCA, 1990)

a. *Antennas*

Communication signals can be received and transmitted through several antennas which include:

- Four earth coverage horns (ECHs); two for receive and two for transmit
- A 61-beam waveguide lens receive multibeam antenna (MBA) with an associated beam forming network; provides selective coverage and jamming protection
- Two 19-beam waveguide lens transmit antennas with beam forming networks; produce selected antenna patterns which conform to the network of ground receivers
- A high-gain gimballed dish transmit antenna (GDA) for spot beam fixed coverage
- UHF antennas for the SCT; a bow tie for receive and a cross dipole for transmit.

These antennas provide a range of patterns from earth coverage to very high gain narrow beams. The DSCS III satellite antenna capability allows a wide variety of strategic and tactical users on the system.

Each antenna can be connected to various channels in a number of combinations. Channels one and two can be commanded from the ground to transmit over a 19-beam MBA or the GDA. Channels three and four can either connect to a ECH or share a 19-beam MBA with channels one or two during transmission. Channel four can also transmit over the GDA. Channels one through four connect to either a ECH or the 61-beam MBA during reception. Channels five and six are dedicated to ECHs during transmission and reception.

b. Transponder and Amplifier Design

The six-channel transponder operates in the SHF frequency spectrum on the DSCS III satellites. Channels one and two have 40 watt travelling wave tube amplifiers (TWTAs). The remaining four channels have 10 watt TWTAs (some DSCS III satellites have been equipped with 10 watt solid state amplifiers).

All channels are protected by some level of back-up. Channels one and two have redundant low noise amplifiers (LNAs), tunnel diode amplifier limiters (TDALs), translator subassemblies, driver amplifiers, and travelling wave tube high power amplifiers (TWT HPAs). In addition, local oscillator sources are provided from a redundant frequency generator assembly. (DCA, 1984, 4-29)

Channels three through six are also protected, but less heavily. These channels share backup TDALs, translator assemblies, driver amplifiers, and TWTAs. Channels three and four, as well as five and six, share only one set of backup components. All channel components are nuclear hardened in accordance with Joint Chiefs of Staff (JCS) guidelines.

Another notable feature of the DSCS III satellite transponder is its "bent pipe" design. The SHF transponder does not process any incoming signal other than translating frequency.

2. Frequency Plan

Since 1983, the DSCS III satellite frequency plan has undergone slight modifications. Figure 2 depicts the six DSCS III channels along with their respective frequency allocation for satellites eight through fourteen.

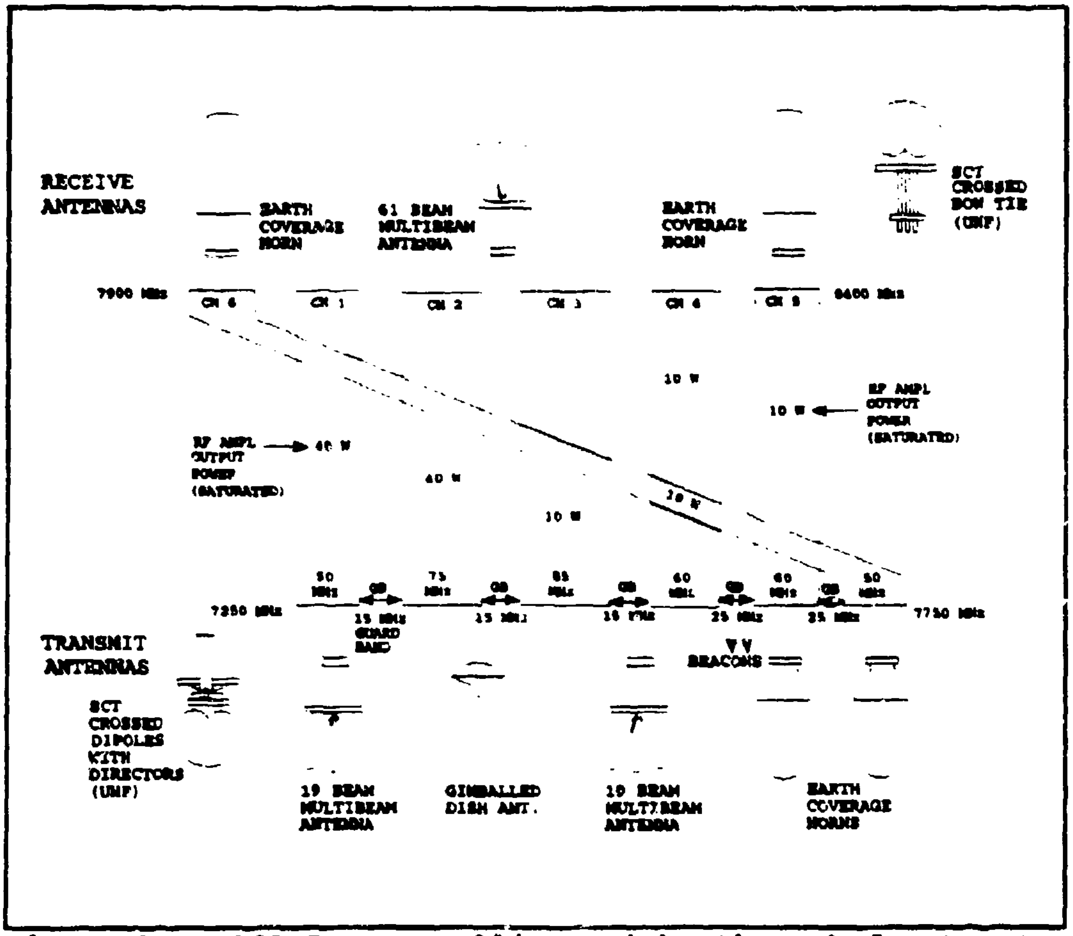

Figure 2. DSCS III (satellites eight through fourteen) Frequency Plan (SPAWAR, 1993, p. 3-5)

The DSCS III satellites one through seven provide channel bandwidths of 60, 60, 85, 60, 60, and 50 MHz for channels one through six, respectively. (Martin, 1991, p. 111) Satellites

eight through fourteen provide 30 MHz more bandwidth with new channel bandwidths of 50, 75, 85, 85, 60, and 50 MHz, respectively.

3. Jam Resistant Circuits

The DSCS III satellite communication payload can provide two types of service to users -- stressed (jam resistant) and unstressed. In the stressed mode, a transponder channel is saturated and Spread-Spectrum Multiple Access (SSMA) modulation is utilized. The stressed channel provides maximum protection against jamming and nuclear scintillation. However, stressing a channel severely limits the permissible data rate of users. In the unstressed mode, the transponder channel is not saturated and high capacity, wideband communications are possible. The unstressed channel is not protected by possible jamming or scintillation.

C. DSCS MANAGEMENT

The Defense Information Systems Agency (DISA) is responsible for the management of the DSCS communications network. DISA directs all of the communications activities of the DSCS satellites through the use of DSCS Operation Centers (DSCSOCs). These centers perform real-time control over satellites in a particular geographical area. (Finney, 1990, p.1) DSCSOCs also act as "gateways" to serve as an interconnect between users and the main elements of the DISA.

Satellite on-orbit maneuvers and control are performed by the Air Force. These functions can be conducted at either the Space Operations Center in Colorado Springs, Colorado, or the Satellite Test Center in Sunnyvale, California.

D. CURRENT USERS

The DSCS III satellite constellation supports an ever increasing amount of users in today's expanding global communication network. (Williams, 1993, p. 8) The major communities supported by DSCS include:

- Air Force Satellite Control Network (AFSCN)
- Unified and Specified Commander-In-Chief (CINC) commands
- White House Communications Agency (WHCA)
- Diplomatic Telecommunications Service (DTS)
- Defense Information Systems Agency (DISA)
- Intelligence community
- Joint Chiefs of Staff (JCS)
- National Emergency Airborne Command Post (NEACP)
- Ground Mobile Forces (GMF)
- Defense Dissemination System (DDS)
- Navy SHF equipped ships and shore sites.

III. NAVAL USE OF THE DSCS III SYSTEM

A. HISTORY

In 1963 the United States (U.S.) Navy installed and tested SHF terminals aboard selected platforms in support of the North Atlantic Treaty Organization (NATO) requirements at shore sites and on flagships. In 1965, the U.S. Navy established an SHF development program in support of Joint Task Force (JTF) flagship requirements. (NAVCOMTELCOM, 1992, p. 1-5) In early 1976, the Navy realized that it needed high-capacity SHF satellite communications to support platforms that towed passive acoustic sonar arrays. On 14 June 1976, the Chief of Naval Operations (CNO) defined the operational requirement to provide SHF satellite communications (SATCOM) capability to the Surveillance Towed Array Sensor System (SURTASS). (SPAWAR, 1993, p. 2-7)

By 1990, the Navy had six designated flagships and selected SURTASS ships equipped with permanent DSCS SHF SATCOM capability. In the spring of 1990, the CNO realized that the Navy needed to improve its means for high-capacity joint communications and initiated an effort to rapidly introduce additional SHF SATCOM capabilities into the fleet. Operation DESERT SHIELD/STORM accelerated the introduction of SHF SATCOM into the Navy. It reinforced the need for an SHF SATCOM

capability on aircraft carriers and amphibious flagships to satisfy minimum tactical command and control (C2), intelligence and war-fighting communications requirements, and improve Joint, Allied and NATO communications interoperability. (Naval Space Command, 1992, p. 1-2)

In order to meet the urgent SHF requirement during Operation Desert Shield/Storm, the Navy obtained and modified U.S. Air Force AN/TSC-93B Ground Mobile Force (GMF) SHF SATCOM vans and installed them on aircraft carriers and amphibious flagships deploying to the Persian Gulf. The modified SATCOM vans were designated "QUICKSAT". The introduction of these terminals into the fleet officially marked the beginning of Phase I of the Navy's SHF SATCOM fielding plan. Phase II of the fielding plan is being initiated currently and includes an improved shipboard terminal.

The Navy's three-phase shipboard terminal plan for providing SHF SATCOM capability to the fleet is defined as follows:

- Phase I: Modified AN/TSC-93B GMF SHF SATCOM terminals on aircraft carriers and selected amphibious flagships. These terminals use a four foot diameter AS-3399/WSC-6 stabilized tracking antennas

- Phase II: Commencing this year (Fiscal Year 1994), an AN/WSC-6(V)4 terminal will replace Phase I terminals. The Phase II terminal contains computer-controlled smart digital multiplexers and is capable of Time Division Multiple Access-Demand Assigned Multiple Access (TDMA-DAMA) as well as Frequency Division Multiple Access (FDMA). Seven foot diameter antennas will replace the older four foot antennas

- Phase III: Commencing in Fiscal Year 1996, a variant AN/WSC-6(V)XX terminal will be implemented capable of providing a full spectrum of SHF SATCOM services.

B. CURRENT OPERATIONAL USE OF DSCS III

1. Shore Based Facilities

a. *Satellite Communication Facilities (SATCOMFACs)*

The U.S. Navy terminates its shipboard SHF SATCOM links at operational DSCS shore sites. A majority of these shore sites are Naval Satellite Communication Facilities (NAVSATCOMFACs). The remainder of the shore sites are comprised of Army-owned DSCS Operation Centers (DSCSOCs). There are three primary types of earth terminals in use at the shore sites supporting Navy DSCS-SHF SATCOM.

(1) AN/FSC-78(V). The AN/FSC-78(V) is a fixed SHF SATCOM heavy terminal (HT) capable of transmitting and receiving signals simultaneously. It is the standard DSCS heavy terminal with a maximum output of 10000 watts and is used worldwide at major nodal communications centers. It is capable of uplinking and downlinking 15 carriers of digital data using FDMA, TDMA, or SSMA. It is also designed to accommodate both analog and digital interfaces. The AN/FSC-78(V) provides a radiated antenna signal of 500 MHz bandwidth at a maximum Effective Isotropic Radiated Power (EIRP) of 94 decibels referenced to one watt (dBW) and a gain-to-noise temperature (G/T) ratio of 39 decibels per degree Kelvin

(dB/°K). It transmits and receives X-band signals using a 60-foot diameter, high-efficiency parabolic reflector mounted on an elevation over azimuth configured pedestal. (NAVCOMTELCOM, 1992, p. 2-22)

(2) AN/GSC-39(V). The AN/GSC-39(V) is a transportable or fixed SHF SATCOM terminal with electrical characteristics similar to those of the AN/FSC-78(V). It is the standard DSCS medium terminal (MT) with a maximum output of 10000 watts and is interchangeable with the AN/FSC-78(V). It is capable of uplinking and downlinking 15 carriers of digital data using FDMA, TDMA, or SSMA and also accommodates both analog and digital interfaces. The AN/GSC-39(V) provides a radiated antenna signal of 500 MHz bandwidth at a maximum EIRP of 92 dBW and a G/T ratio of 34 dB/°K. It transmits and receives X-band signals using a 38-foot diameter, high-efficiency parabolic reflector and a pedestal housing the drive mechanism. (SPAWAR, 1993, p.4-4)

(3) AN/GSC-52(V). The AN/GSC-52(V) is a fixed or mobile state-of-the-art medium terminal (MT) used for communications with the DSCS III and NATO III satellites. It is a high-capacity, high altitude electromagnetic pulse (HEMP) protected terminal with a maximum output of 10000 watts. It is capable of uplinking and downlinking 15 carriers of digital data using FDMA, TDMA, or SSMA and can accommodate both analog and digital interfaces. The AN/GSC-52(V) provides a

radiated antenna signal of 500 MHz bandwidth at a maximum EIRP of 91 dBW and a G/T ratio of 33 dB/°K. It transmits and receives X-band signals using a 38-foot diameter, high-efficiency parabolic reflector. Terminal operations are facilitated by a centralized control, monitor, and alarm (CMA) subsystem, which features computer-aided control and monitoring. (NAVCOMTELCOM, 1992, p. 2-20)

b. Standard Tactical Entry Points (STEPS)

The U.S. Navy uses both SATCOMFACs and DSCSOCs to terminate SHF links. The baseband equipment used at these shore-based facilities varies from one gateway to the next. This inconsistency has caused several problems for U.S. Naval ships as they have moved from one gateway to another while crossing into a new area of operations. The need for a standardized interface for all DSCS users prompted the Joint Chiefs of Staff (JCS) to task the Defense Information Systems Agency (DISA) to develop a Standard Tactical Entry Point (STEP) which would provide an expanded and standardized set of equipment at DSCS tactical gateway earth terminals. (DISA, 1994, p. 1)

STEPs will be located in each of the five DSCS satellite areas. A STEP will ensure interoperability among DSCS users and will provide them access to the Defense Information Systems Network (DISN). (DISA, 1994, p. 4) A global network of STEP terminals will coincide with the JCS

Global Grid concept and will provide tactical users access to the global Command and Control, Communications and Computers and Intelligence (C4I) support structure. The C4I structure is comprised of worldwide transmission networks, voice, imagery, video, data switching systems, and baseband systems such as the Worldwide Military Command and Control System (WWMCCS). (SPAWAR, 1993, p. 4-20) The STEP design will allow military forces such as a Joint Task Force (JTF) to deploy anywhere in the world with assurance that prepositioned assets will be available to support communications.

The STEP system design builds on the present DSCS gateways by adding a uniform equipment suite at selected sites. The STEP design has been separated into three phases. A near-term design will use military inventories and commercial off-the-shelf equipment. It will consist of 10 STEPS, two per DSCS area, and will be capable of supporting four naval ships per satellite area. One STEP per satellite area will have the capability of supporting TDMA-DAMA. The mid-term design will implement new DSCS subsystems that will be available by 1998. The far-term design will contain new technology and equipment to improve the STEP efficiency and meet expected growth requirements. (DISA, 1994, p. 5)

2. Current Shipboard Terminals

a. *AN/WSC-6(V)1*

The AN/WSC-6(V)1 is used on the SURTASS-equipped ships and is capable of a maximum output of 8000 watts. It uses a binary phase shift keying (BPSK) modem that can operate at data rates of 75 bps to 50 kbps. The AN/WSC-6(V)1 is capable of uplinking and downlinking carriers of data using FDMA, TDMA, CDMA, or SSMA. It provides a radiated antenna signal at a maximum EIRP of 72 dBW and a G/T ratio of 10 dB/°K. The AN/WSC-6(V)1 transmits and receives X-band signals using a 4-foot diameter, radome enclosed, high-efficiency parabolic reflector. (NAVCOMTELCOM, 1992, p. 2-24)

b. *AN/WSC-6(V)2*

The AN/WSC-6(V)2 is used on flag and selected fleet ships and is very similar to the (V)1 model with a few notable exceptions. The AN/WSC-6(V)2 uses a spread spectrum anti-jamming modem and a low rate multiplexer to provide 32 kbps operation per channel unit. The (V)2 transmits and receives X-band signals using a single or dual 4-foot diameter, radome-enclosed, high-efficiency parabolic reflector. (NAVCOMTELCOM, 1992, p. 2-24)

c. *Modified AN/TSC-93B*

The modified AN/TSC-93B, referred to as QUICKSAT, has been adapted for various shipboard installations and is capable of a maximum output of 500 watts. In 1991, the

significant modifications included: one BPSK modem, three low speed time division multiplexers (LSTDM), and the AN/WSC-6(V) antenna system. The initial QUICKSAT terminal operated at 16 kbps. Today, due to increased communication requirements and the procurement of better commercial modems, QUICKSAT terminals are operating at 256 kbps. Each QUICKSAT terminal provides a radiated antenna signal at a maximum EIRP of 70 dBW and a G/T ratio of 15 dB/°K. It transmits and receives X-band signals using the same AN/WSC-6(V) 4-foot diameter, radome enclosed, high-efficiency parabolic reflector. (Naval Space Command, 1992, p. 2-9)

d. AN/WSC-6(V)4

The AN/WSC-6(V)4 shipboard terminal is the replacement system for many of the Phase I (QUICKSAT) terminals. This Phase II variant of the AN/WSC-6(V) terminal replaces the 8000 watt klystron amplifier with a Commercial Off-the-Shelf (COTS) 300 watt Travelling Wave Tube Amplifier (TWTA). The AN/WSC-6(V)4 is equipped with a COTS FDMA modem capable of 1544 kbps and a TDMA Demand Assigned Multiple Access (DAMA) modem that can operate at a composite data rate up to 256 kbps. (Naval Space Command, 1994, p. 2-6) The AN/WSC-6(V)4 is scheduled to use dual 7-foot diameter, high-efficiency parabolic reflectors.

3. DSCS Communication Circuits

In 1991 when the Navy implemented QUICKSAT, the primary objective was to obtain a means of communicating with joint forces during Operation Desert Shield/Storm. Specifically, the Navy needed an expedient means of obtaining the Air Tasking Order (ATO) from the Air force. During the campaign, the Navy relied on personal messenger service to get the ATO. The ATO was often several hours late which severely hindered target coordination with the Air Force. This problem, combined with the inability to communicate with joint forces over SHF satellite links, led the Navy to immediately acquire Air Force AN/TSC-93B terminals. Table I below depicts the initial QUICKSAT circuits.

TABLE I. 1991 QUICKSAT SHF CIRCUITS (Lord, 1993)

Circuit	Data Rate
Air Tasking Order (ATO)	2.4 kbps
Orderwire	300 bps
Secure Telephone Unit (STU-III)	2.4 kbps
Dual Advanced Narrowband Digital Voice Terminal (ANDVT)	2.4 kbps
Manual Relay Center Modernization Program (MARCEMP)	600 bps
Fleet Broadcast	1.2 kbps
Worldwide Military Command and Control System (WWMCCS)	2.4 kbps

After Operation Desert Shield/Storm, the Navy was left with SHF QUICKSAT terminals and no long range plan on how to utilize SHF satellite communications. Prior to the introduction of SHF SATCOM, the Navy primarily relied on High Frequency (HF) and Ultra High Frequency (UHF) communications. All critical circuits were established on these communication mediums. The Navy never saw a need for extensive SHF SATCOM. Even during Operation Desert Shield/Storm, SHF SATCOM was only viewed as a means of delivering the ATO and talking over a secure telephone link. However, immediately after the campaign, the Navy quickly learned the benefits of high-capacity communications.

Operation Desert Shield/Storm proved to be an experience without precedence for military communications. Total military communications traffic exceeded 160 Megabits per second (Mbps). The DSCS constellation accounted for nearly 125 Mbps of that total. (Cook, 1992, p. 3) This tremendous surge in information exchange pushed each of the military services to capitalize on all available communication assets for the future. SHF satellite communications for the Navy took on a whole new emphasis. Today, the Navy uses numerous circuits on SHF satellite links, far exceeding the initial aggregate data rate of 16 kbps. Table II illustrates the type of circuits the Navy now uses over SHF satellite communications.

TABLE II. CURRENT NAVY SHF CIRCUITS (SPAWAR, 1994, p. 4)

Circuit	Data Rate
Contingency Tactical Air Control Center (TACC) Automated Planning System (CTAPS)	9.6 kbps
Orderwire	300 bps
Secure Telephone Unit (STU-III)	2.4 kbps
Dual Advanced Narrowband Digital Voice Terminal (ANDVT)	2.4 kbps
Manual Relay Center Modernization Program (MARCEMP)	600 bps
Fleet Broadcast	1.2 kbps
Worldwide Military Command and Control System (WWMCCS)	2.4 - 9.6 kbps
Digital Subscriber Voice Terminal (DSVT) KY-68	16 kbps
Joint Defense Intelligence Support Services (JDISS)	2.4 - 56 kbps
Defense Secure Network (DSNET)	9.6 kbps
Joint Maritime Command Information System (JMCIS)	9.6 kbps
Joint Worldwide Intelligence Communications Systems (JWICS)	56 - 512 kbps
Plain Old Telephone System (POTS)	8 or 16 kbps
Streamlined Automated Logistics Transmission System (SALTS)	9.6 kbps
Tactical Teletype (TTY)	75 or 300 bps
Tactical Environmental Support System (TESS-3)	2.4 - 9.6 kbps
Video Information Exchange System (VIXS)	112 kbps
Voice, Video, Fax, Data Terminal	9.6 kbps
Wideband Secure Voice (WBSV)	16 kbps

4. Naval Use of DSCS III Transponders

In 1991 when the Navy expanded its SHF communications requirements, channels on the DSCS system were already allocated to specific users. Although the Navy was already a user and was allocated a SURTASS Navy subnet, the subnet was not large enough to handle the additional SHF requirements. The Navy had to take whatever empty transponder space they could get on the satellites. As a result, the Navy was assigned additional portions of various channels on various satellites. As the SHF communication requirements grew from 1991 to present, DSCS channels were destressed and more space on the DSCS system was allocated to the Navy. Table III shows the current allocations by geographical area along with assigned aggregate data rates and transponder power percentage.

TABLE III. DSCS CHANNEL ALLOCATIONS (Naval Space Command, 1994, p. 2-3)

Satellite	Data Rate	Channel	% Power
Eastern Atlantic	512 kbps	One	50
Western Atlantic	256 kbps 82 kbps	One Six	20 20
Eastern Pacific	128 kbps	Six	50
Western Pacific	512 kbps	One	50
Indian Ocean	512 kbps	One	50

Today the Navy operates and exercises full control over all operations within the revised subnet on DSCS as specified above. DISA allocates the bandwidth, data rates, and power allocations.

C. ADVANTAGES DSCS III OFFERS THE U.S. NAVY

1. Anti-Jamming Capability

The DSCS III satellite offers several anti-jamming capabilities. First, the multibeam antenna (MBA) provides selective coverage with steerable beams and nulls out active jammers. Second, DSCS III contains a unique SHF/S-band TT&C subsystem with jammer locating equipment. The TT&C link uses data encoding and interleaving to increase the probability of uninterrupted reception through hostile scintillation environments. Finally, the satellite is capable of operating in a stressed mode whereby a transponder channel is saturated and spread spectrum multiple access (SSMA) is used.

2. Survivability

The DSCS III satellites were designed to withstand a highly radiated space environment. First, all of the channel components on the DSCS III satellites are nuclear hardened in accordance with JCS guidelines. Second, all channels have redundant components in case of any of the primary components fail. Finally, each channel contains a Tunnel Diode Amplifier and Limiter (TDAL) which prevents a jammer from oversaturating the transponder and burning out the Travelling Wave Tube

Amplifier (TWTA) or Solid State Amplifier (SSA). Figure 3 depicts a block diagram for one DSCS channel and illustrates the location of the TDAL.

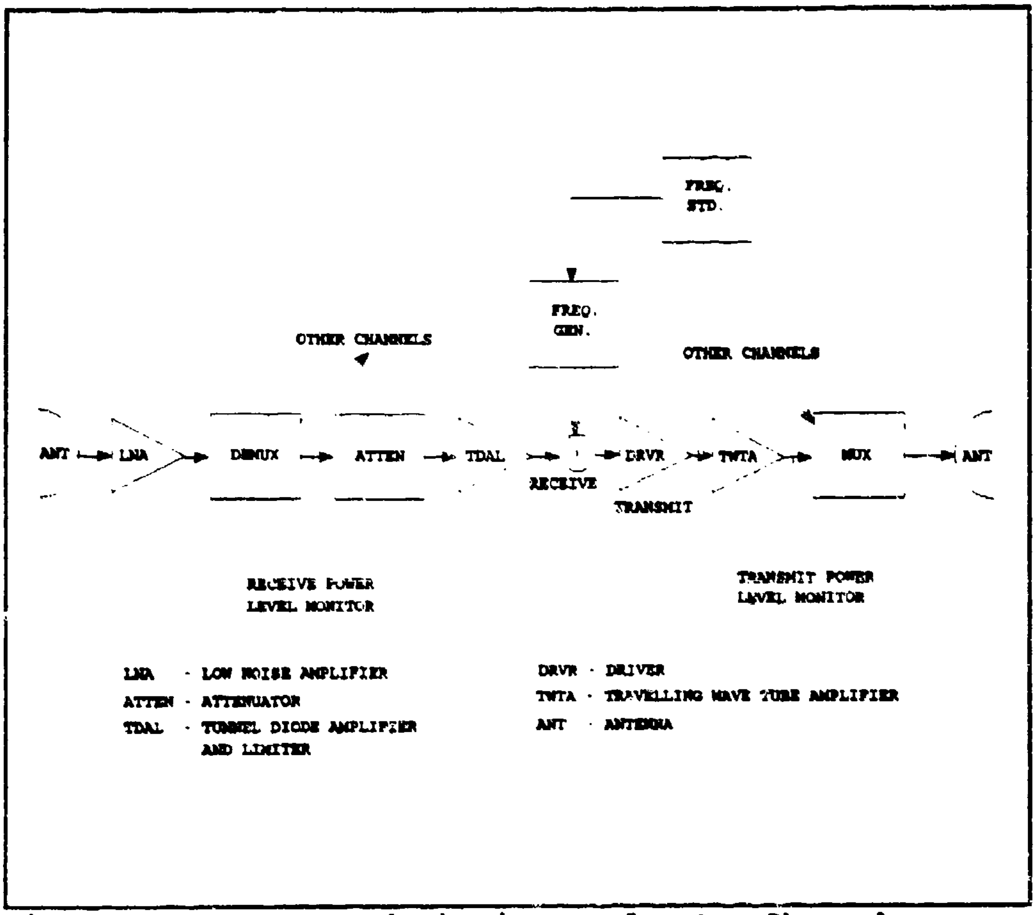

Figure 3. DSCS III Block Diagram for One Channel (DCA, 1984, p. 4-31)

3. Timeliness/Availability

The DSCS III system is owned and operated by the military. The satellite network will always be available to military users on demand.

4. Joint/Allied Interoperability

The DSCS has been used by the Air Force, Army, and numerous Department Of Defense (DOD) agencies for several years. DSCS SHF circuits have been a stable means of interoperable communications among military users. The Navy's recent expansion into DSCS SHF communications insures joint interoperability. In addition, NATO countries have access to the DSCS. Therefore, the DSCS system also represents a means of allied interoperability.

5. Ocean Coverage

The DSCS III system offers worldwide coverage, including ocean areas. Ocean coverage is vital to the Navy.

6. Mobility

The DSCS III system as a whole is very mobile. First, the satellites themselves are quite versatile and can be controlled and moved around in orbit (limited movement). Second, the ground earth stations can be placed at various locations around the world. Finally, tactical user terminals can be used anywhere in the world.

7. Military Infrastructure

The DSCS network was initially developed in 1967. It consisted of a limited number of satellites and ground stations. Since that time, a fully operational network of military-owned satellites, ground earth stations, and user terminals has developed. The DSCS is a military-owned and

operated functional SHF satellite network for the Navy to plug into and communicate.

D. DISADVANTAGES OF DSCS III

1. Limited Capacity due to Satellite Power

The transponder power on the DSCS III satellites is limited and must be divided between the numerous users described in Chapter II. The Navy's allocation of transponder power is quite small and limits communication links to a maximum data rate of 512 kbps in selected ocean areas.

2. Shipboard Antennas

The DSCS was initially designed for fixed users with large antennas. The Navy is a mobile user with very small antennas. The Navy's use of four foot antennas has caused numerous problems. First, the four foot diameter antennas severely limit communication capacity. Second, shipboard antennas are large and bulky and cannot be mounted at the very top of a ship's mast. The antennas are typically located below the mast superstructure and experience blockage problems as they track and lock onto the DSCS III satellites while the ship is moving. The introduction of dual tracking seven foot antennas in the near future will help alleviate some problems, but the Navy is still a disadvantaged user.

3. Designed for Large Fixed Terminals

As mentioned above, the DSCS was initially designed for fixed users with large antennas. These fixed terminals

have a very high gain-to-noise temperature (G/T) ratio and high effective isotropic radiated power (EIRP) output capable of sending several megabits of information through the satellite network. In comparison, the Navy terminals have significantly low G/T ratios and EIRPs which severely limit communication capabilities.

4. Lack of Fleet Experience

The quick introduction of QUICKSAT and Phase II SHF SATCOM systems into the Navy has caused some problems. First, operators of the equipment have received very limited training. (COMNAVAIRLANT, 1994) The Navy was not prepared for such a quick expansion of SHF SATCOM and did not plan a training course for system operators[1]. Second, the Navy is far behind the other military services when it comes to experience with DSCS SHF SATCOM. The Air Force and Army have used DSCS for several years and are experienced operators. The Navy, for all practical purposes, joined the other services in using DSCS in 1991 with little or no experience. This lack of experience has led to cutover problems and delays as long as 24 hours as ships shift SHF communications from one DSCS satellite to another as they transition between Area of Operations (AOR). (McHale, 1994) Finally, the Navy's lack of experience has led to configuring incompatible DSCS baseband

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[1]A training program has just been initiated in 1994 to help educate operators.

equipment. Incompatible equipment configurations has prevented expeditious activation of joint circuits as naval platforms transition between adjacent AORs. (USCINCCENT, 1994)

IV. FUTURE USE OF DSCS IN THE NAVY

A. DSCS IN THE NAVY'S SATCOM ARCHITECTURE

The numerous advantages that the DSCS network offers the Navy, as noted in Chapter IV, reveal the importance of this system in the Navy's current and future SATCOM architecture. One of the most important advantages is its ability to link joint and allied forces together. Operation Desert Shield/Storm highlighted the Navy's limited SHF SATCOM interoperability with Joint and Allied/NATO forces, including Marine Corps forces ashore. (Naval Space Command, 1992, p. 1-3) There is currently no other satellite communications system that is as universal as the X-band DSCS network. The Navy needs the DSCS network in order to stay interoperable in the future battlespace.

Another important aspect of the DSCS network to the Navy is its communications capability. The DSCS network currently provides protected 32 Kbps circuits and unprotected 512 Kbps circuits.

1. Protected Low Data Rate (LDR) Circuits

A significant advantage that the DSCS network offers the Navy is its capability to provide protected circuits. Until the EHF MILSTAR network becomes fully operational, the DSCS is the only satellite communications medium that is

capable of providing circuits protected from jamming and scintillation. Currently the Navy is limited to 32 Kbps operation using DSCS protected circuits due to old OM-55 spread spectrum multiple access (SSMA) modems.

A new modem currently in development that may alleviate the problem of the limited data rate while maintaining a certain degree of protection is the Universal Modem-CU2 (UM-CU2). The UM-CU2 uses orthogonal frequency hopping (OFH), power efficient modulation, and coding and interleaving to achieve a data rate output of close to 2.048 Mbps. (Kullstam, 1994, p. 1)

a. The Threat

The importance of having protected circuits must not be downplayed when considering threats around the world. The recent collapse of the Soviet Union may have brought about a rather false sense of euphoria among political leaders. The United States is feeling more secure than ever before in recent history. Hostile threats, however, still exist around the globe. The uncertainty still present around the world today is best illustrated in former Secretary of Defense Dick Cheney's statement:

> The world is still a dangerous place. In addition to a major regional conflict in the Persian Gulf, we have seen renewed ethnic, religious, and national violence in Europe, Asia, and elsewhere... We face serious regional contingencies -- threats that may be triggered by any number of events, are difficult to identify in advance, and could be made more dangerous by the spread of high-technology weapons. (U.S. DOD, 1993, p. v)

b. *The Type of Threat*

The type of threats that the Navy could encounter in future regional conflicts include: hostile jammers, scintillation via nuclear burst, and intercept and exploitation of satellite communications. (CNO, 1994) Although these threats could be found anywhere in the world, they will most likely be experienced with countries that once were affiliated with or benefitted from the fall of the Soviet Union. Such countries as Iran, Iraq, North Korea, China, and even former states of the Soviet Union could be capable of jamming, intercepting and exploiting satellite communications. (U.S. DOD, 1993, p. 2)

2. Unprotected Wideband Circuits

Another significant advantage that the DSCS offers the Navy is its ability to provide high capacity circuits. Currently the DSCS network offers the Joint Task Force Commander at sea high data rate circuits for command and control. Although the Navy is currently limited to a maximum data rate of 512 Kbps in selected ocean areas, the DSCS III constellation can provide greater capacity to the Navy.

There are currently two forces that will contribute to higher capacity DSCS communications for the Navy in the near future. First, the Navy is aggressively pursuing improved Phase II ship terminals using high performance TDMA-DAMA and FDMA modems. Second, the Defense Information Systems Agency

(DISA) Military Satellite Communications (MILSATCOM) Systems Office (MSO) is studying the possibility of moving fixed users off the DSCS network in order to free up bandwidth and power for mobile users.

a. Phase II Terminals using Improved Modems

The Navy's new Phase II shipboard terminal with seven foot diameter antennas will have an average effective isotropic radiated power (EIRP) of 66 dBW and a gain-to-noise temperature (G/T) ratio of 18.5 dB/^{o}K. (DISA JIEO, 1993, p. 3) This new terminal combined with the 1.544 Mbps FDMA modem and 256 Kbps TDMA-DAMA modem will allow the Navy greater capacity SHF communications over the DSCS network. The new Phase II terminals and modems will allow the Navy to transfer information over DSCS T-1 data links in the near future.

b. DSCS Bandwidth and Power Reallocations

The DISA MILSATCOM Systems Office (MSO) recently conducted a study of DSCS loading and recommended that several fixed users be moved off the DSCS network and onto terrestrial cable or fiber. (Guiar, 1994) This would allow more power and bandwidth for small mobile users such as the Navy. The study further revealed that current requirements for protected circuits over DSCS cannot be met. Therefore, in addition to moving fixed users off the DSCS network, the MSO study recommends upgrading ground terminals and satellites in order to increase protected capacity throughput.

B. FUTURE REQUIREMENTS FOR DSCS

The increasing emphasis in recent years on fighting joint battles in an information intensive environment has led the Navy to forecast high capacity SHF circuit requirements for all naval ships. Table IV below depicts expected circuit requirements for a single aircraft carrier in the near future.

TABLE IV. FUTURE AIRCRAFT CARRIER CIRCUIT REQUIREMENTS (CNO, 1994)

Circuit	Data Rate
Contingency Tactical Air Control Center (TACC) Automated Planning System (CTAPS)	9.6 kbps
Secure Telephone Unit (10 STU-III phones)	24 kbps
Worldwide Military Command and Control System (WWMCCS)	4.8 kbps
Joint Defense Intelligence Support Services (JDISS)	9.6 kbps
Defense Secure Network (DSNET)	9.6 kbps
Joint Maritime Command Information System (JMCIS)	9.6 kbps
Joint Worldwide Intelligence Communications Systems (JWICS)	460.8 kbps
Plain Old Telephone System (POTS - 5 phones)	80 kbps
Tactical Environmental Support System (TESS-3)	2.4 kbps
Video Information Exchange System (VIXS)	112 kbps
Wideband Secure Voice (WBSV)	16 kbps
TOTAL:	738.4 kbps

The future requirements for DSCS SHF communications in the Navy will exceed the current maximum data rate allocation of 512 Kbps for all ships per ocean area. The Navy will need more than 512 Kbps per ship in each ocean area. At the current rate of SHF SATCOM expansion, the Navy will need to have over 1.544 Mbps allocated over the DSCS network per ocean area.

Recent preparations for contingency operations in southwest Asia and ongoing Mediterranean operations in support of Operation Deny Flight have highlighted the increased need for SHF satellite communications connectivity. (CNO, 1994) The current Phase I and Phase II shipboard terminals using four foot diameter antennas do not provide enough capacity to meet critical communication requirements.

V. COMMERCIAL SATELLITE SYSTEMS USED BY THE NAVY

A. INTERNATIONAL MARITIME SATELLITE (INMARSAT)

1. History

In 1972, the Intergovernmental Maritime Organization (IMO) began to study the development of an international maritime satellite system. This system would provide higher quality communications, lower delays, higher reliability and privacy, and higher data rates for communications between commercial ships and the international public communications networks over existing terrestrial radio links. In April 1975, the IMO convened an international conference with 48 nations represented to establish the system and the organization to operate the system, the International Maritime Satellite (INMARSAT) organization. The initial membership of the INMARSAT organization included 26 nations, increasing to 67 by December 1992. (Comparetto, 1993, p. 3)

The initial INMARSATs were leased satellites already in orbit or in development. On 1 February 1982, the INMARSAT organization began service using three leased satellites from the Maritime Satellite (MARISAT) constellation[2]. A satellite

[2]MARISAT satellites were first launched in 1976 and were designed by Hughes Aircraft Company for the Communications Satellite (COMSAT) Corporation. They are commonly known in the Navy as GAPFILLER satellites.

from the Maritime European Communication Satellite (MARECS) organization and a satellite from the International Telecommunications Satellite (INTELSAT) organization were added to the INMARSAT constellation by January 1983.

The INMARSAT system today employs a network of 11 satellites in geostationary orbit located over the East and West Atlantic, Indian, and Pacific Oceans. The constellation consists of four INMARSAT II satellites[3], which now serve as the primary INMARSAT satellites, supplemented by three MARISATs, one MARECS, and three INTELSATs, all on reserve.

2. Communication Capabilities

The INMARSAT II uses frequencies 1.5 to 1.6 GHz (L-band) for communication with ships and frequencies 3.6 to 6.4 GHz (C-band) for communication with shore stations. The communication subsystem contains two four-channel L-band and two single-channel C-band receivers, one single-channel L-band and one four-channel C-band transmitter. Thus, a shore station uses a single uplink C-band channel and a single downlink L-band channel to communicate with a ship. A ship uses one of four uplink L-band channels and one of four downlink C-band channels to communicate with a shore station. The first ship-to-shore channel is for high speed data (56

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[3]INMARSAT II satellites were first launched in 1990 and were developed by British Aerospace (primary contractor), Hughes Aircraft (payload design) and subcontractors in France, Japan, West Germany, and Canada.

kbps), the second for low power ship terminals, the third for small, mobile INMARSAT-A terminals, and the fourth for very low power ship terminals such as INMARSAT-C terminals, emergency beacons, and aircraft. (Martin, 1991, p. 72)

a. *Payload Configuration*

The communications payload on an INMARSAT contains two subsystems using a total of eight 30 watt travelling wave tube amplifiers (TWTAs). Figure 4 illustrates the INMARSAT II communications payload.

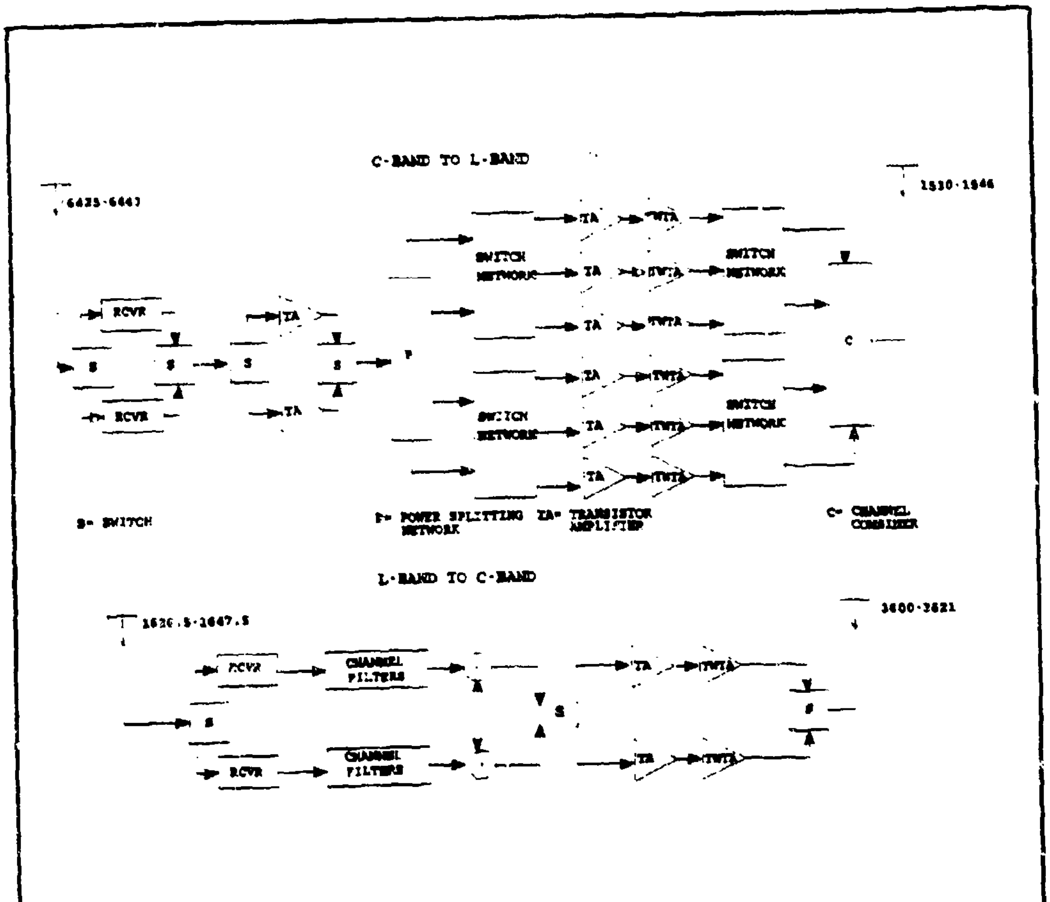

Figure 4. INMARSAT II Communications Payload (Martin, 1991, p. 71)

The INMARSAT II contains a total of four antennas: two L-band (transmit and receive) and two C-band (transmit and receive). Each antenna is hard-wired to an assigned transmitter or receiver and cannot be changed from a ground station controller. All antennas are earth coverage, cup-backed crossed dipoles with circular polarization. The four antennas are described as follows:

- L-band transmit: 61-element array, beam shaped to give increasing gain from center to edge of earth
- L-band receive: nine-element array
- C-band transmit: seven-element array
- C-band receive: seven-element array.

b. Frequency Plan

The single uplink C-band and downlink L-band channel of INMARSAT II is configured for a bandwidth of 16 MHz. The satellite receives the C-band uplink channel between 6425 and 6441 MHz. The L-band downlink channel is transmitted using frequencies in the range of 1530 to 1546 MHz. The four uplink L-band and downlink C-band channels use bandwidths of 4.5, 4.5, 7.3, and 3.2 MHz. The satellite receives the L-band uplink channels between 1626.5 and 1647.5 MHz with .5 MHz guard bands. The C-band downlink channels are transmitted to shore sites using frequencies 3600 to 3621 MHz with .5 MHz guard bands. (Martin, 1991, p. 71)

3. INMARSAT Management

The INMARSAT organization, composed of representatives from all member nations, reviews activities and considers long-term policies for the INMARSAT system. The organization meets every two years. A smaller organization, composed of the eighteen largest members, meets three times a year and provides direction to a Directorate, which carries out day-to-day activities. (Martin, 1994, p. 89)

The INMARSAT system is composed of four segments. The first segment was defined above and consists of leased or owned satellites. The second segment consists of Coast Earth Stations (CESs) and are owned and operated by INMARSAT members. INMARSAT CESs are located in different countries throughout the world and act as the communications gateway between the INMARSAT system and shore public switched telephone networks. Some CESs provide Telemetry, Tracking and Control (TT&C) facilities for the INMARSAT satellites. There are more than 30 CESs operating in different ocean regions today. Earth stations owned and operated by the United States representative, Communications Satellite (COMSAT) Corporation, are located at Southbury, Connecticut, Santa Paula, California, and Anatolia, Turkey.

The third segment consists of Ship Earth Stations (SESs) owned and operated by shipowners. SESs transmit and receive signals to and from the satellites using L-band frequencies. Currently there are four types of SESs:

- **INMARSAT-A:** A medium suitcase-sized terminal with a one meter diameter parabolic antenna capable of supporting fax and data up to 9.6 kilobits per second (kbps) and one analog voice channel (or a single 56 kbps data rate channel)

- **INMARSAT-B:** A terminal similar to INMARSAT-A except the analog voice channel is replaced by a 16 kbps digital voice channel

- **INMARSAT-C:** A small suitcase-sized terminal with a hemispheric, non-pointing antenna, less than half a meter in diameter, capable of storing and forwarding digital data at a rate of 600 bps

- **INMARSAT-M:** A small suitcase-sized terminal with a half meter diameter parabolic antenna capable of supporting fax and data up to 2.4 kbps and one digital voice channel at 6.4 kbps. (Comparetto, 1993, p. 2)

The final segment of the INMARSAT system consists of the primary control facility for TT&C. The central control for the network is exercised from the INMARSAT Operations Control Center in London.

4. Current Users

The INMARSAT system today is utilized by over 67 nations around the world. Specific users include: oil tankers, cargo ships, research ships, naval ships, yachts, fishing vessels, passenger liners, oil platforms, arctic weather stations, trucking companies, aircraft, and land mobile units. Simply stated, the INMARSAT system is a very diverse network that can be used by anyone with a SES.

B. INTERNATIONAL TELECOMMUNICATIONS SATELLITE (INTELSAT)

1. History

In August of 1964, an International Telecommunications Satellite (INTELSAT) Consortium was formed among participating nations with the sole purpose of producing, owning, managing, and using a global communications satellite system. In February 1973, a formalized structure for INTELSAT was established and the consortium was changed to an organization. In December 1992, the INTELSAT organization was comprised of over 124 member nations with the Communications Satellite (COMSAT) Corporation acting as the United States signatory. (Comparetto, 1993, p. 1)

The first satellite in the INTELSAT constellation, INTELSAT I (also known as Early Bird), launched in April 1965. Today the INTELSAT system employs a network of over 21 geostationary satellites located in 20 orbital positions over the Atlantic, Indian, and Pacific Oceans and supports direct communication links among 180 countries, territories, and dependencies. Since 1965, the INTELSATs have undergone numerous modifications and improvements. The active satellites currently in orbit today consist of five types of INTELSATs: INTELSAT V, INTELSAT VA, INTELSAT VI, INTELSAT K, and INTELSAT VII.

2. Communication Capabilities

The communication capabilities of each currently active INTELSAT varies from one satellite to the next. Each payload configuration and frequency plan differs as well. The differences in communication capabilities among the active INTELSATs are depicted in the tables found the Appendix.

All of the current INTELSATs (except INTELSAT K) utilize frequencies in the range of four to six MHz (C-band) and 12-14 MHz (Ku-Band). INTELSAT V is the oldest in the series with eight satellites of this type in orbit. INTELSAT VA is a modification of the INTELSAT V design with five satellites in orbit. The primary goal of INTELSAT VA was to improve performance, reliability, and communications capacity over INTELSAT V in order to keep ahead of the traffic growth in the Atlantic region. (Martin, 1991, p. 61) INTELSAT VI represents an improved technology satellite which uses newly allocated portions of the frequency spectrum adjacent to existing C and Ku-bands, active onboard switching, increased frequency reuse, and increased effective radiated power (ERP) in some channels. There are five INTELSAT VI satellites currently in orbit. The INTELSAT K satellite was designed as a supplement to the regular series of INTELSATs. There is only one INTELSAT K satellite and it is used over the Atlantic Ocean to provide additional Ku-band only service.

The newest member of the INTELSAT constellation is INTELSAT VII. The two current INTELSAT VII satellites in

orbit today serve as replacements for INTELSAT V and INTELSAT VA satellites and provide specialized services such as business communications to small antennas. The INTELSAT VII satellite is more flexible than INTELSAT VI and is capable of serving a variety of geographical locations using an increased set of antenna beams. INTELSAT VII also has a higher performance than INTELSAT VI, thereby increasing the usefulness of smaller earth stations. (Martin, 1991, p. 77)

3. INTELSAT Management

Policy and long-term plans for the INTELSAT constellation are formulated once every two years by representatives from all governments that are members of the INTELSAT organization. Financial, technical, and operational matters are decided upon by telecommunication representatives once a year. Design, development, operation, and maintenance issues are decided upon five times a year by a group of members known as the Board of Governors. Most members of this group represent countries or groups of countries with large ownership percentages of INTELSAT. (Martin, 1991, p. 83)

The INTELSAT system can be divided into three segments. The first segment consists of the INTELSAT satellites owned and operated by the INTELSAT organization. The second segment consists of the ground terminals. There are a wide array of terminal types and designs with antenna sizes ranging from 3.5 meters to 18 meters. The majority of

INTELSAT terminals now in use correspond to either the Standard A, B, or C designs. (Comparetto, 1993, p.2) The standard terminal characteristics are as follows:

- Standard A: Medium to high capacity (24 voice circuits or greater) terminal used for international public communications using C-band. Antenna diameter ranges from 15 to 18 meters
- Standard B: Low to medium capacity (24 voice circuits or less) terminal used for international public communications using C-band. Antenna diameter ranges from 10 to 12 meters
- Standard C: Medium to high capacity (24 voice circuits or greater) terminal used for international public communications using Ku-band. Antenna diameter ranges from 12 to 15 meters.

The final segment of the INTELSAT system is the control center. The INTELSAT constellation uses six TT&C terminals located in Maryland, Hawaii, Australia, Italy, Germany, and China. They fall under the direction of the INTELSAT Operations Center in Washington, D.C.

4. Current Users

Today the INTELSAT network is used by a wide range of users from various countries. INTELSAT transponders are both leased out and sold to member countries. INTELSAT leases capacity in increments of nine, 18, 36, 54, or 72 MHz. By the end of 1991, over 40 transponders were leased and 60 were purchased. (Comparetto, 1993, p. 3)

INTELSAT is capable of handling telephone, telegraph, data, and television traffic. Telephone is the major portion

of the traffic. The majority (60%) of INTELSAT traffic originates in the Atlantic region while the remainder of the traffic is divided between the Pacific and Indian Ocean regions.

VI. NAVAL USE OF COMMERCIAL INMARSAT AND INTELSAT

A. HISTORY

In 1989, the Navy had installed a limited number of INMARSAT-A terminals on select ships to provide a communications interface with U.S. flag merchant ships. These terminals were receive-only systems and marked the beginning of the Navy's use of INMARSAT. In 1991, Operation Desert Shield/Storm established the need for new user priorities and over 50 fully capable INMARSAT-A terminals were added to the fleet. Today there are over 203 INMARSAT-A terminals in the fleet. (Hartung, 1994)

The Navy's use of INTELSAT has been virtually nonexistent up until the last two years. In 1992, the Navy evaluated the use of an INTELSAT C-band terminal providing duplex, 1.544 Mbps shore-to-ship and 772 Kbps ship-to-shore links. The evaluation took place on board the USS GEORGE WASHINGTON (CVN 73) during an exercise called CHALLENGE ATHENA I. This exercise demonstrated that INTELSAT could be used for several high capacity circuits such as live motion video teleconferencing and imagery. (CNO, 1994)

During this same time, the Navy was also testing the use of an INTELSAT Ku-band terminal aboard the USS MT. WHITNEY (LCC 20). The ship used a General Telephone and Electronics

(GTE) terminal to test the use of an INTELSAT Ku-band spot beam providing 1.544 Mbps service. (COMSAT, 1994, p. 2)

B. CURRENT OPERATIONAL USE OF INMARSAT AND INTELSAT

1. INMARSAT Circuits

In 1989, the initial INMARSAT-A terminals were receive-only terminals used to pick up distress signals from U.S. flag merchant ships. Today there are a wide variety of circuits that the Navy uses over INMARSAT. Table V below shows some of the circuits now used over INMARSAT-A terminals.

TABLE V. INMARSAT CIRCUITS (SPAWAR, 1992, p. 74-92)

Circuit	Data Rate
Streamlined Alternative Logistics Transmission System (SALTS)	9.6 kbps
Armed Forces Satellite Transmitted Radio Service (AFSTRS)	9.6 kbps
CNN Broadcast News	9.6 kbps
Broadcast Facsimile	9.6 kbps
Interactive Voice/Video/Facsimile Data (VVFD)	9.6 kbps
Commercial Public Telephone	9.6 kbps
Secure Voice STU-III	2.4 kbps

2. CHALLENGE ATHENA II

The proof of concept demonstration of using INTELSAT during CHALLENGE ATHENA I was such a great success that it

prompted the Navy to expand the testing of INTELSAT in CHALLENGE ATHENA II which is currently ongoing. Exercise CHALLENGE ATHENA II uses a 36 MHz C-band global beam to provide a duplex, digital private-line service to the USS GEORGE WASHINGTON. The shipboard terminal uses a 2.4 meter antenna to receive and transmit 1.544 Mbps shore-to-ship and 1.152 Mbps ship-to-shore. These high data rates support the major objectives of providing intelligence communications, imagery, multiple-line telephone service, and telemedicine to a ship at sea for extended deployment. Preliminary reports from CHALLENGE ATHENA II have indicated great success using the INTELSAT network. (CNO, 1994)

C. ADVANTAGES INMARSAT AND INTELSAT OFFER THE U.S. NAVY

1. High Capacity and Surge Capability

INMARSAT and INTELSAT offer tremendous communication capabilities to the Navy. The use of these systems will insure the Navy has additional communication links to handle excessive communications such as those seen during Operation Desert Shield/Storm. In addition, INTELSAT is capable of supporting high capacity communications (1.544 Mbps), as demonstrated in exercises CHALLENGE ATHENA I/II.

2. Low Initial Investment

Unlike the DSCS network, the government does not have to purchase INMARSAT and INTELSAT satellites, launch vehicles, and earth stations when using these commercial systems. The

Navy simply has to purchase a user terminal (which is significantly cheaper than a DSCS terminal) and lease circuits or lease/buy a transponder.

3. Wideband Services

Although the DSCS network is capable of supplying wideband service to its users, the Navy is currently limited to a maximum data rate of 512 Kbps per ocean area. The total 512 Kbps must be split up between all ships in the area. Thus, if eight ships were in the same ocean area equally using the DSCS network, each ship would be limited to a total data rate of 64 Kbps. INTELSAT on the other hand is currently capable of supplying a data rate of 1.544 Mbps per ship in the same ocean area[4].

4. Personal Communications

The use of INMARSAT and INTELSAT allow a sailor for the first time aboard a ship at sea to call spouses and other loved ones at home. The average cost for a telephone call from the USS GEORGE WASHINGTON in the English Channel to the U.S. during CHALLENGE ATHENA II was only 50 cents per minute.

5. Augmentation to MILSATCOM

One of the most significant advantages that INMARSAT and INTELSAT offers the Navy is its ability to enhance the current MILSATCOM architecture. The commercial C, Ku, and L-

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[4]The Navy must share a 50 Mhz band on the DSCS III satellites among all users. INTELSAT leases out entire bands up to 72 Mhz.

band services would supplement the already existing suite of UHF and SHF satellite systems.

D. DISADVANTAGES OF INMARSAT AND INTELSAT

1. Lack of Anti-Jamming Capability

INMARSAT and INTELSAT were planned for the commercial sector. These systems do not contain any countermeasures directed against nuisance threats, low power jammers, or strategic, high power jammers. In addition, terminals associated with these systems are not designed for low probability of interception and detection. Both INMARSAT and INTELSAT are extremely vulnerable to outside jamming.

2. C-band Interference Problems

A major concern associated with using INMARSAT and INTELSAT C-band communications is interference. First, shipboard C-band terminals operate at frequencies that are very close to onboard electronic combat system frequencies, such as those associated with the SLQ-32 threat reaction jammer and SPS-40/49 radars. If the C-band antenna is too close to these jammers or radars, there is a high probability of electromagnetic interference (EMI). The British ship Sheffield experienced this interference during the Falklands War and failed to pickup an incoming Exocet missile. Second, a high percentage of countries around the world use C-band communications. As C-band SATCOM equipped Navy ships get close to shore, there is a high probability that onboard C-

band terminals could get interference from terrestrial microwave communications. (Aberle, 1994)

3. Antenna Size and Stabilization

Current INMARSAT and INTELSAT antennas are not designed for automatic continuous 360 degree tracking. As the antennas go beyond 360 degrees, the antenna cable gets wrapped around the center axis and must be unwound. In addition, in order to obtain the 1.544 Mbps of information over INTELSAT using C-band, large 8 foot diameter antennas must be used. Large diameter antennas are a problem aboard ships where space is a premium.

4. Timeliness

The use of INMARSAT and INTELSAT requires careful planning and advance scheduling. Leasing large capacity circuits (up to 1.544 Mbps) in the continental U.S. takes around 21 days. A request for more complex requirements could take as long as 230 days. (Miller, 1994) Operation Desert Shield/Storm proved that these lengthy processing times could be shortened, but at significantly higher costs. In addition, the shortened processing time is still not acceptable for a tactical situation requiring immediate connectivity.

Leasing or purchasing entire transponders on INTELSAT take even longer than the 230 day request for service. INTELSAT transponders that are capable of global connectivity are usually leased out or purchased five to seven years before

the satellite is placed in orbit. Thus, the Navy would have to purchase a transponder today on a new INTELSAT VIIA satellite in order to get uncontested use of that transponder in the year 1999.

5. Lack of INTELSAT Ocean Coverage

The INTELSAT network was designed to serve international communities around the world. The Ku-band transponder on the satellite system was specifically planned for heavily populated land masses, not ocean areas. The Ku-band steerable beam antenna on current INTELSATs misses a significant portion of the ocean areas. In addition, the C-band earth coverage antennas on current INTELSATs do not capture all of the ocean regions.

6. Competition with Commercial Circuits

Unless an entire transponder is leased or purchased, portions of a transponder are leased out or time on a transponder is purchased. The Navy must submit a request and compete with all other users of the satellite system. There is no guarantee that the circuits requested will be available.

7. Treaty/Landing Rights Issues

The use of INMARSAT and INTELSAT in foreign countries poses several problems. First, in order to communicate in a foreign country using a fixed satellite system (FSS), Host Nation Approval (HNA) must be established. Depending on the country involved, a HNA could take anywhere from three months

to two years. (DISA MSO, 1994, p. 3-6) Second, once a HNA is established, the host nation controls and operates the earth ground station. If a regional conflict developed in which the host nation was involved, there is no guarantee that the ground earth station will remain operational. During Operation Desert Shield/Storm, a ground earth station in Saudi Arabia was abandoned by the operators once the war started. (Baciocco, 1994)

A final issue of concern is treaty rights. INMARSAT and INTELSAT are restricted to a certain degree regarding the types of service that they may provide for military use because of their international obligations. The only INTELSAT agreement that specifically addresses military use is Article III of the INTELSAT Agreements. This article states that INTELSAT may "be utilized for the purpose of specialized telecommunications services, either international or domestic, other than for military purposes." (Comparetto, 1993, p. 9) The military has gotten around this clause by simply pointing out that specialized telecommunications services require special hardware packages on INTELSATs that do not currently exist. Thus, INTELSAT does not currently offer these services and therefore they are not an issue with respect to the Department of Defense (DOD) use of INTELSAT services.

The restrictions regarding the use of INMARSAT services by DOD organizations are not as clear as those of INTELSAT. The primary clause in the INMARSAT agreements that

pertains to DOD use of INMARSAT services is contained in Article 3(3) which states, "The organization shall act exclusively for peaceful purposes." (Comparetto, 1993, p. 10) In this clause, the phrase "peaceful purposes" has been interpreted a number of different ways and remains unclear even today. The Navy's interpretation of this clause is "peaceful purposes does not exclude military activities so long as those activities are consistent with the United Nations (UN) Charter". (Comparetto, 1993, p. 11) INMARSAT's interpretation of this clause is that a ship shall use the INMARSAT system exclusively for peaceful purposes, but in the event that the vessel becomes involved in any armed conflict, the shipboard INMARSAT terminal shall be used for distress and safety communications. Although the INMARSAT interpretation is more restrictive than the Navy's interpretation, INMARSAT has not enforced its position to date.

8. Rain Attenuation with Ku-band

A significant problem experienced with super high frequency satellite communications is a drop in transmit and receive link margins due to interference from water droplets in the atmosphere. The higher the frequency on the electromagnetic spectrum, the more susceptible satellite communications are to rain attenuation. Frequencies in the Ku-band are extremely vulnerable to rain attenuation. The Navy could experience a significant degradation in Ku-band

satellite communications at sea if weather conditions are not clear.

9. Narrow Bandwidth with INMARSAT

INMARSAT is a very low capacity system (56 Kbps) that uses very narrow bandwidths. The widest band on an INMARSAT is 7.3 MHz. The narrow bandwidth severely limits the data rate and the amount of data that the Navy can place over the system.

10. Operational Security

The use of Ku-band steerable spot beams by the Navy would require coordination with the satellite operator to maintain coverage. During tactical operations, the disclosure of force position and point of intended movement (PIM) would violate operational security.

VII. FUTURE USE OF COMMERCIAL SATELLITES IN THE NAVY

A. INMARSAT AND INTELSAT IN THE NAVY'S SATCOM ARCHITECTURE

INMARSAT and INTELSAT also have a significant importance in the Navy's current and future SATCOM architecture as illustrated by the advantages noted in Chapter VI. The greatest advantage that these systems offer the Navy is their surge capability. In future information intensive conflicts, the Navy will need to capitalize on INMARSAT and INTELSAT in order to meet all of the expected communication requirements. Current studies reveal that by the year 2003, two major regional conflicts (MRCs) will require a wartime communications capability of over 1061 Mbps. (Guiar, 1994)

1. Mobile Unprotected Wideband Surge

INTELSAT offers the Navy the capability of providing high capacity communications for circuits requiring little to no anti-jamming protection. Currently the Navy cannot rely on any other satellite communications medium to handle high capacity surge circuits such as video teleconferencing and image transfers. INTELSAT will be able to handle current and future requirements for unprotected wideband surge circuits.

2. Localized Unprotected Narrowband Surge

INMARSAT provides the Navy with unprotected narrowband surge circuits. During Operation Desert Shield/Storm,

administrative and logistical information and morale and welfare circuits placed a tremendous strain on existing satellite communications. The Navy realized this strain and started using INMARSAT to free up stressed MILSATCOM circuits. INMARSAT provides surge capacity for narrowband circuits requiring no protection such as the Streamlined Alternative Logistics Transmission System (SALTS), Armed Forces Radio, and CNN news.

3. Mobile Direct Dial DSN/PSTN Access

A significant advantage that both INMARSAT and INTELSAT offer the Navy is an alternative means of connecting a ship to the Defense Switching Network (DSN) and Public Switched Telephone Network (PSTN). Over the past year as the Navy has struggled to become proficient at using the DSCS III SHF network, INMARSAT and INTELSAT were critical as backup DSN/PSTN circuits. During regional cut-overs, DSCS communications would be down for several hours. INMARSAT and INTELSAT allowed the Navy to communicate with ground earth stations to get the DSCS communications link back on line.

INMARSAT and INTELSAT also provide a vital role in establishing contact with the Defense Data Network (DDN). Access to the DSN and PSTN allows the Navy to transfer electronic mail over the DDN, tap into Internet resources, and become a player in the "information superhighway".

B. FUTURE REQUIREMENTS FOR INMARSAT AND INTELSAT

1. Near-Term INMARSAT Circuits

The requirements for INMARSAT in the future continue to expand as the United States military prepares for future information intensive regional conflicts. The Navy has placed a renewed emphasis on "information warfare". Table VI below shows some of the expected circuits that will be used over INMARSAT in the near future.

TABLE VI. NEAR-TERM REQUIREMENTS FOR INMARSAT (SPAWAR, 1994)

Circuit	Data Rate
Streamlined Alternative Logistics Transmission System (SALTS)	9.6 kbps
Armed Forces Satellite Transmitted Radio Service (AFSTRS)	9.6 kbps
CNN Broadcast News	9.6 kbps
Broadcast Facsimile	9.6 kbps
Interactive Voice/Video/Facsimile Data (VVFD)	9.6 kbps
Commercial Public Telephone	9.6 kbps
Secure Voice STU-III	2.4 kbps
Compressed Broadcast Video	300 kbps
High Speed Data	56/64 kbps
Internet/DDN E-mail Access	9.6 kbps

2. INMARSAT Terminals

The success of adding INMARSAT to the current suite of satellite communications has prompted the Navy to replace current INMARSAT-A terminals with their digital voice upgrade INMARSAT-B shipboard stations. The phase-out of INMARSAT-A terminals is scheduled to begin in 1996. INMARSAT-B terminals will provide multi-channel service with a total capability of 150 Kbps. (CNO, 1994) In addition, the Navy is currently testing INMARSAT-M terminals for future deployment. The INMARSAT-M terminals will provide 4.8 Kbps voice service and 2.4 Kbps data service at a considerable cost savings. (Hartung, 1994)

3. Near-Term INTELSAT Circuits

The requirements for INTELSAT in the future also continue to expand. The success of exercise Challenge Athena I and the current positive feedback from Challenge Athena II reveal that INTELSAT can be used for transferring imagery, medical information, limited intelligence data, and other high capacity communications now and in the future. (CNO, 1994) INTELSAT has allowed the Navy to expand its communications into areas that were once never considered in the old UHF MILSATCOM network. A Navy ship in the future will have the capability of receiving high capacity imagery over enemy territory, critical x-rays, Computerized Axial Tomography (CAT) scans, and Magnetic Resonance Imaging (MRI) on sailors

at sea, and conduct real-time video teleconferencing. Table VII below shows some of the expected circuits that will be used over INTELSAT in the near future.

TABLE VII. Near-Term Requirements for INTELSAT (CNO, 1994)

Circuit	Data Rate
Intelligence/Imagery	772 kbps
Medical (X-rays, CAT scans, MRIs)	56 kbps
Public Affairs Office	56 kbps
TRAP Broadcast	9.6 kbps
Video Teleconferencing	128/384 kbps
Secure Voice STU-III (20 units)	320 kbps
Commercial Public Telephone (20 Units)	192 kbps
Joint Defense Intelligence Support Services (JDISS)	56-64 kbps

C. COMMERCIAL SATELLITE COMMUNICATIONS INITIATIVE (CSCI) - A RECOMMENDATION ON THE FUTURE USE OF COMMERCIAL SATELLITES

1. Background of CSCI

In 1991, the White House approved a U.S. Commercial Space Policy known as the Commercial Satellite Communications Initiative (CSCI) program that encouraged private investment expansion in space. The House Appropriations Committee (HAC) added an additional $15 million dollars to the program to fund an initiative by the Assistant Secretary of Defense for

Command, Control, Communications, and Intelligence (C3I) to aggressively pursue an expanded role for commercial satellites in the Department of Defense (DOD) SATCOM architecture. The funds were used to award contracts to corporations with expertise in commercial satellite communications to study the long-term communications requirements of the Department of Defense and to determine how well current and projected commercial systems met those needs. (DISA MSO, 1994, p. 1-1)

Government communication requirements were derived from the Integrated Satellite Communications Database (ISDB). The ISDB defines worldwide peacetime, contingency, and on-call requirements and divides these requirements into General Purpose (GP), Core, and Hard Core circuits. GP circuits are defined as having no anti-jam protection and include logistic, administrative, intelligence, common-user networks, and counternarcotics requirements. (CJCS MOP 37, 1992, p. GL-5) Core circuits are defined as having varying degrees of anti-jam protection and limited low probability of intercept/low probability of deception (LPI/LPD) requirements. (DISA MSO, 1994, p. ES-1) Hard Core circuits are defined as having survivability against the maximum threat for jamming, high-altitude electromagnetic pulse (HEMP) attack, scintillation, and includes LPI/LPD, global coverage, and near-real-time access and network reconfiguration. (CJCS MOP 37, 1992, p. GL-5) The CSCI study did not include the extreme robust strategic and tactical Hard Core requirements due to the

limited anti-jamming and LPI/LPD capabilities found in commercial systems.

On July 13, 1992 contracts were awarded to the Communications Satellite (COMSAT) Corporation, Hughes, and Space Systems/LORAL. COMSAT and Hughes were chosen to develop Fixed Satellite Service (FSS) architectures. COMSAT and Space Systems/LORAL (SS/LORAL) were chosen to develop Mobile Satellite Service (MSS). The Mobile Satellite Service is defined as satellite service between ships, aircraft, or land mobile terminals and other mobile users or fixed users on land. (DISA MSO, 1994, p. ES-1) The MSS applies Naval users and will be the focus for the remainder of this section.

2. CSCI Recommendation for Mobile Satellite Service

Space Systems LORAL (SS/LORAL) and the Communications Satellite (COMSAT) Corporation determined tha[illegible] General Purpose requirements (106 total) and 38 Core requ[illegible] (out of 329) could be met by the current and projected Mobile Satellite Services. SS/LORAL determined that the best way to meet these requirements was to use a mixed satellite architecture consisting of Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geosynchronous Earth Orbit (GEO) satellites. These satellites would all use a bent pipe design to permit easy interoperability among systems. Furthermore, earth station gateways for these systems would have access to the Defense Information Systems Network (DISN), government network

operations, and the Public Switched Telephone Network (PSTN). (DISA MSO, 1994, p. 4-1)

a. *Implementation of Mobile Satellite Service*

SS/LORAL recommended that the LEO system should be comprised of the 48 satellite Globalstar network due to be operational by 1998. This system will use L-band and S-band (UHF) frequencies with gateways operating in the C-band. The satellite antenna design will provide asymmetrical radiation patterns to improve performance. (DISA MSO, 1994, p. 4-3)

The MEO system of choice was the 12 satellite Odyssey constellation due to be operational by 1998. Odyssey is being developed by the TRW Corporation and will use L-band and S-band frequencies with gateways operating at Ka-band. (DISA MSO, 1994, p. 4-3)

The recommended GEO system is the current four satellite INMARSAT constellation providing ocean coverage. The next generation INMARSAT satellite will provide five spot beams for concentration of communications in areas of interest and a dedicated L-band package. (DISA MSO, 1994, p. 4-3)

SS/LORAL also recommended that the Mobile Satellite Service be augmented with Fixed Satellite Services (FSS) such as INTELSAT and the Pan American Satellite PANAMSAT to handle high data rate users exceeding 64 kbps. PANAMSAT was launched on 15 June 1988 and provides C-band service to Central and South America, and Ku-band service to the United

States, Europe and transatlantic ocean areas. A new PANAMSAT is planned for launch in 1994 that covers the Pacific Ocean area and contains 48 transponders (twice as many as the first PANAMSAT). Another PANAMSAT covering the Indian Ocean area is planned for 1995. (Martin, 1991, p. 65) Table VIII below shows SS/LORAL's vision of how various data rate circuits onboard a ship will be assigned to the mix of commercial satellite systems.

TABLE VIII. ASSIGNMENT OF SHIP CIRCUITS TO COMMERCIAL SATELLITE SYSTEMS (DISA, 1993, P. 2-7)

	Non-Voice Circuits				Voice Circuit
	≤ 2.4 kbps	2.4-9.6 kbps	9.6-64 kbps	64-1544 kbps	
1994	INMARSAT	INMARSAT	INMARSAT INTELSAT	INTELSAT	INMARSAT
By 1998	INMARSAT Globalstar Odyssey	INMARSAT Odyssey	INMARSAT INTELSAT PANAMSAT	INTELSAT PANAMSAT	INMARSAT Globalstar Odyssey

b. *Leasing Fixed Satellite Service Transponders*

The Mobile Satellite Service (currently INMARSAT) is acquired on a dial-up pay-per-minute basis. Fixed Satellite Service (currently INTELSAT) is acquired by leasing individual circuits. Space Systems LORAL (SS/LORAL) and the Communications Satellite (COMSAT) Corporation recommend that,

in the near future, the Department of Defense lease entire transponders on INMARSAT and PANAMSAT and bundle circuits and trunks onto these transponders. The cost of leasing a transponder is significantly less than the total cost of the individual circuits. (DISA MSO, 1994, p. 5-4) In fact, the Defense Information Systems Agency MILSATCOM Systems Office recently obtained congressional funding to analyze the leasing of entire transponders on commercial satellite systems. (Aberle, 1994)

To meet the projected general purpose peacetime and surge requirements by the year 2000, SS/LORAL and COMSAT recommend leasing approximately 40 C-band and Ku-band transponders. (DISA MSO, 1994, p. 5-2) Non-preemptive circuits will first be assigned to the leased transponder. Transponder power and bandwidth that is not required for non-preemptible circuits will be reserved for preemptible service and controlled by the Joint Staff. This will allow the Department of Defense to manage the use of the leased resources and ensure sufficient preemptible service to handle a deployed Joint Task Force or surge requirements. (DISA MSO, 1994, p. 5-4)

3. New Technologies

As part of the CSCI study, several new technologies and innovative configurations were analyzed for feasibility and future implementation. Some of the more promising new

technologies for future implementation on commercial satellite systems are discussed below.

a. Asynchronous Transfer Mode (ATM)

As Department of Defense communication requirements continue to grow at exponential rates, faster, more efficient ways of transferring data must implemented. Asynchronous Transfer Mode (ATM) is a technique whereby fixed-sized data cells are transferred over high-speed switches. During the CSCI study, the ATM concept was tested to show the viability of extending the Global Grid or Defense Information Systems Network capabilities into a tactical theater via satellite at 45 Mbps. (DISA MSO, 1994, p. 7-1)

b. Compact User Pulled Intelligence Dissemination (CUPID)

During the CSCI study, Hughes used a new high speed modem and proprietary software to establish a client/server architecture on a UNIX system and disseminated high speed imagery and command data from a hub site (7.6 meter antenna) to a small tactical site (one meter antenna). In addition, low speed imagery and gun camera video data was transmitted from the small tactical site to the hub site. The system was called the Compact User Pulled Intelligence Dissemination (CUPID) concept. The high speed imagery was sent at a data rate of two megabits per second and provided a 1024 x 1024 image with 8 bits per pixel within 30 seconds. The low speed imagery was sent at a data rate of 128 kilobits

per second and provided an image within five minutes. (DISA MSO, 1994, p. 7-2) The CUPID concept could have several spinoffs for the U.S. Navy where imagery is critical and onboard space is limited.

c. *Personal Communications Satellites (PCS) and Handheld Terminals*

The goal of Low Earth Orbit (LEO) personal communications satellites (PCS) is to allow mobile users worldwide connectivity using handheld terminals. COMSAT is currently investigating the market demand and the cost of development of LEO PCS systems. There still remains tremendous uncertainty over which PCS system will emerge and what the final cost will be for this network. (DISA MSO, 1994, p. 7-4) However, the idea of using lightweight handheld terminals to communicate worldwide is ideally suited for ships at sea.

d. *Direct Broadcast Satellite (DBS) Services*

Direct Broadcast Satellite (DBS) services refers to using a medium to high power geosynchronous satellite to transmit a high data rate to small terminals using antennas less than 18 inches in diameter. Although there are several Direct Broadcast Satellites in production and some in orbit, the recent on-orbit pair of high-powered satellites built by Hughes represent some of the latest advances in DBS technology. These satellites are capable of delivering a total of 150 channels of video to small mobile terminals.

Some of the more noteworthy technological advances on the Hughes DBS satellites include:

- 16 transponders powered by 120 watt travelling wave tube amplifiers (TWTAs) for high power downlink transmission that can be reconfigured to provide eight channels with 240 watts of power
- High gain lightweight graphite antennas that feature a specially contoured surface that requires only one, rather than multiple, feedhorns to provide an optimal signal
- State-of-the-art digital technology to compress multiple video signals into each transponder. (Hughes, 1993)

The latest DBS technology could be very beneficial to Department of Defence agencies, especially the U.S. Navy. Naval applications include broadcast of weather, training, entertainment, intelligence, maps, and archive information to deployed ships with one foot diameter antennas and small lightweight terminals. (DISA MSO, 1994, p. 7-6)

e. *Advanced Communications Technology Satellite (ACTS)*

In July 1993, an Advanced Communications Technology Satellite (ACTS) was launched to demonstrate operations using 20-30 GHz frequencies (Ka-band), very narrow spot beams with high radiated power, high gain antennas allowing high data rates into very small aperture terminals (VSATs), broadband digital communications into smaller portable terminals, and adaptive onboard communications processing. (DISA MSO, 1994, p. 7-7) ACTS opens up new opportunities to the U.S. military community.

The success of ACTS testing could provide numerous benefits to small mobile users such as the Navy. First, the use of frequencies in the Ka-band allow an expansion of the radio frequency spectrum and thus an increase in data capacity to satellite systems. Second, high power hopping spot beams and a steerable spot beam concentrate energy on small mobile users and provides a certain degree of LPI/LPD. Third, high gain antennas along with an onboard microwave switch matrix allow wideband operation and high data rate into small VSATs. Finally, ACTS uses an adaptive onboard signal regeneration process which not only regenerates incoming signals but also corrects transmission errors onboard. This onboard process reduces signal attenuation due to rain and enhances small terminal capabilities. (Wright, 1992, pp. 1135-1145)

The new technologies used in ACTS will allow small mobile users to transmit and receive data at rates of up to 25 Mbps. (DISA MSO, 1994, p. 7-7) The Navy, which is limited on shipboard space and will require large data rates in the future, would be a prime candidate for such a system.

f. Interoperable Gateways

Another area that was considered by the CSCI study was the idea of central satellite operation centers capable of handling all satellite communications as well as microwave, HF, cable and fiber links. These centers, known as "teleports" would be owned and operated by the military and

capable of handling all satellite communications including DSCS, INMARSAT, and INTELSAT circuits. (Daspit, 1994)

The concept of transportable gateways was also analyzed in the CSCI study. Moveable gateways would allow easy access to all users around the world. Interoperable and transportable gateways could represent a cost-efficient means of tying INMARSAT, INTELSAT, and DSCS systems together for the Navy.

g. Multi-band Antennas and Tri-band Terminals

The CSCI study also gave attention to the use of tri-band terminals and multi-band antennas. A tri-band terminal with a multi-band antenna will allow users to transmit and receive C, X, and Ku-band communications. The results of the CSCI study reveal that tri-band operation is feasible but still needs more development. Questions still remain over which frequency to use since only one frequency band can be utilized at a time. In addition, modifying antennas to handle tri-band terminals is complicated and degrades overall performance. (DISA MSO, 1994, p. 7-4) As the Navy struggles to find space aboard ships for satellite equipment, tri-band terminals may offer a feasible solution.

4. Custom DSCS Satellite Study

As part of the Commercial Satellite Communications Initiative, Hughes Space and Communications Company examined the feasibility and cost advantages or disadvantages of

supplementing the DSCS constellation with commercially built satellites customized to operate at X-band frequencies. (DISA MSO, 1994, p. 7-9) The custom satellites examined in the study were designed to commercial standards and did not contain any nuclear hardened components, multibeam antennas or anti-jam control links. The satellites carried only general purpose communications and were placed in low-threat regions near the continental United States. The custom satellites were not designed to provide protected service, but Hughes determined that limited resistance to nuisance or tactical jamming threats could be obtained through the use of:

- Spatial isolation using separate spot-beam antennas
- Diversity using terminals pointed at two different satellites
- Channel control units to provide attenuation (gain adjustment)
- Hard-limiters to prevent over saturation. (Soderblom, 1994, pp. 3-4 - 3-13)

As part of the study, Hughes examined user requirements from the Integrated SATCOM Database (ISDB), emerging requirements specified by the Defense Information Systems Agency (DISA), and future requirements from the Defense Information Systems Network (DISN) architecture. (Soderblom, 1994, p. 2-3) Each custom satellite was evaluated on how well it integrated with the current DSCS constellation and met the projected requirements.

An underlying concern of the Hughes study was to determine how well a supplemental satellite would satisfy unmet Navy needs. (Soderblom, 1994, p. 1-1) Hughes determined that the Navy would require at least 49.4 Mbps per ocean area in the near future. (Soderblom, 1994, p. 3-17) The current DSCS satellite constellation only allows the Navy 512 Kbps per ocean region. Thus, several of the custom satellites considered were specifically tailored to meet future Navy requirements over ocean areas.

a. Spacecraft Options

Hughes analyzed four satellite designs each containing X-band transponders. Three of the four options contained transponders using commercial satellite frequencies. Hughes examined commercial transponders operating at Ku, C, and Ka-band frequencies. Transponders operating in the Ku-band were preferred because they encountered less interference from terrestrial systems, offered higher bandwidth, and allowed for a smaller terminal size. Although Ka-band transponders appeared promising, available equipment was limited and associated costs were high. (Soderblom, 1994, p. 3-9)

In the study, Hughes examined four satellite space segment options, but used only two satellite bus designs. In the interest of low cost and simplicity, Hughes considered one bus design for a Delta II launch vehicle (a cylindrical

shaped, dual-spin stabilized spacecraft) and one bus for an Atlas II launch vehicle (a rectangular shaped, three-axis stabilized spacecraft).

(1) Delta-class DSCS-compatible Satellite. The first Delta-class option featured four steerable X-band spot beam antennas and an earth-coverage antenna. It included six DSCS-compatible transponders capable of emulating the DSCS III radio frequency (RF) performance. (Soderblom, 1994, p. 5-2)

(2) Delta-class Option II Satellite. The second Delta-class configuration featured two steerable SHF spot beam antennas and one earth-coverage antenna. It included four DSCS-compatible transponders and three Ku-band transponders. The Ku-band spot-beam payload was designed to provide high data rate service to ships at sea. (Soderblom, 1994, p. 5-6)

(3) Atlas-class DSCS-compatible Satellite. The first Atlas-class option featured four steerable SHF spot beam antennas, one earth coverage horn antenna, and one shaped beam Ku-band antenna. It included eight DSCS-compatible transponders and 24 Ku-band fixed satellite service (FSS) transponders. The Ku-band FSS payload used 50 watt transponders and was designed for high capacity fixed users. (Soderblom, 1994, p. 5-11)

(4) Atlas-class Option II Satellite. The second Atlas-class configuration featured four steerable SHF spot beam antennas, three steerable Ku-band spot beam antennas, one

earth coverage horn antenna, and one shaped beam Ku-band antenna. It included eight DSCS-compatible transponders, 12 Ku-band fixed satellite service (FSS) transponders, and nine Ku-band ship/shore transponders. (Soderblom, 1994, p. 5-15)

b. *Spacecraft Costs*

Hughes considered four procurement options for each of the four satellite choices. The first procurement method was to have the government purchase the entire satellite. The acquisition costs were based on commercial type contracts, milestone payments, and on orbit delivery of the spacecraft. Costs included spacecraft, satellite insurance and launch services. Costs did not include operation and maintenance. (Soderblom, 1994, p. 7-1)

The second procurement option was to have the government develop the spacecraft, have a contractor build it, and let the government lease the satellite. Development costs included payload design, bus modifications, system engineering, program management, launch services, mission analysis and associated fees. The lease cost was based on a ten year lease and included satellite recurring construction costs, insurance, and launch services. Lease costs were determined by calculating the required contractor internal rate of return on the capital investment costs for a ten year period. Transponder usage fees and operation and maintenance support costs were excluded. (Soderblom, 1994, p. 7-1)

The third procurement option was to allow a contractor to build and own the satellite and lease the spacecraft to the government. Costs associated with this option were the same as the second option minus government developmental costs but plus contractor design fees.

The final procurement option was to allow a contractor to build and own the satellite and lease transponders to the government and other users. Transponder lease costs were determined by dividing the total lease cost by the percentage of transponders allocated to each service (X-band, Ku-band FSS and Ku-band spot-beam). (Soderblom, 1994, p. 7-2) Table IX shows the costs that Hughes calculated for each satellite option using the four procurement methods.

TABLE IX. SATELLITE OPTION COST SUMMARY ($ MILLION) (Soderblom, 1994, p. 7-1)

	Acquisition Cost	Government Developed/ 10 Year Lease	Contractor Developed/ 10 Year Lease	Shared 10 Year Lease
Delta-class Option I	$186.1	$350.4	$390.0	N/A
Delta-class Option II	$192.0	$359.9	$402.0	$201.0
Atlas-class Option I	$276.4	$526.4	$578.0	$153.8
Atlas-class Option II	$287.8	$545.4	$598.0	$153.8

Several conclusions can be drawn from the results of the Hughes cost analysis. The most important conclusion is that the government would save several million dollars if it leased transponders on a commercially built Atlas-class satellite versus purchasing, developing and leasing, or just leasing a Delta-class or Atlas-class satellite. Although usage fees were not considered in the cost analysis, it is assumed that they would not be so great as to change the conclusions drawn from the analysis.

c. *Recommended DSCS Satellite Constellation*

After a careful cost-performance analysis, Hughes recommended leasing transponders on an Atlas-class satellite with a shared Ku-band fixed satellite service (FSS) and spot-beam payload. This option offered the lowest cost, the best value, met the needs of the current DSCS users, and provided commercially-managed leading edge services and commercial surge capability. (Soderblom, 1994, p. 8-4) Hughes also determined that the current DSCS satellite constellation could be reduced to three DSCS-III satellites and one or more custom satellites. This reduced DSCS III constellation would still meet most core requirements and allow continuous operation of the DSCS satellite system well into the year 2012 without having to build any additional DSCS III satellites. (Soderblom, 1994, p. 2-1)

It is important to point out that the custom satellite option recommended by Hughes was prepared for the Defense Information Systems Agency (DISA). Although Hughes analyzed satellite options that would meet Navy requirements in ocean regions, specific needs of the Navy were addressed in the study. Hughes did not analyze the severity of rain attenuation encountered by naval ships using Ku-band satellite communications at sea. Security of the fleet was not considered when Hughes decided on commercially owned steerable Ku-band spot-beams. Finally, the reduction of shipboard terminal antenna sizes were not addressed when selecting transponder amplifiers.

Although the custom DSCS satellite study may have overlooked some important considerations for the Navy, the analysis is valuable in pointing out that a supplemental commercial DSCS satellite offers several advantages. Using shared satellite resources and available bus designs, a cost effective, high performance custom DSCS satellite can be designed and quickly deployed to meet unmet Navy requirements.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The Defense Satellite Communications System (DSCS), International Maritime Satellite (INMARSAT), and International Telecommunications Satellite (INTELSAT) networks all have a place in the Navy's satellite communications architecture. The recent explosion of information and the transfer of high capacity data over the past few years in the Navy has demanded more and more satellite communications bandwidth and power. There is currently no single satellite communications system that can satisfy all of the maritime Command, Control, Communications, Computers and Intelligence (C4I) requirements. In fact, the recent study conducted by the DISA MILSATCOM Office concluded that all of the current military satellite communications combined could not handle all of the requirements listed in the integrated military SATCOM database. (Guiar, 1994)

Each satellite communications system has its unique strengths and weaknesses and plays a specific role in the Navy's SATCOM architecture. A combination of all the systems offers robustness, provides alternate routing for communications restoral and reconfiguration, alleviates overcrowding and possible interference, and provides

protection for critical military circuits. An integrated approach offers the Navy the best of all systems.

The DSCS network provides quick, allied and joint interoperable SHF satellite service with anti-jamming capabilities to the Navy's current suite of satellite communications. It brings with it a reliable infrastructure using a dedicated owned and operated X-band spectrum.

INMARSAT and INTELSAT fill the gaps which the DSCS network lacks in providing adequate capacity. These systems provide high capacity communications and surge capabilities for the Navy's high data rate requirements.

B. RECOMMENDATIONS

The Navy needs to continue using the DSCS network for low capacity protected circuits. As more bandwidth and power on the DSCS III satellites become available for the Navy's use, higher capacity communications should be transferred from the commercial satellite links onto the DSCS network. Every effort should be made to continue moving fixed users off the DSCS network and onto cable, fiber, or high capacity commercial satellite networks thereby freeing up bandwidth and power for disadvantaged mobile users such as the Navy. In addition, in order to meet higher capacity requirements in the future, the Navy needs to obtain dedicated channels on the DSCS III satellites.

The current DSCS network needs vast improvements, and satellites need to be redesigned. The DSCS III satellites that are currently in orbit were designed in 1977. Since that time, a few upgrades have been implemented on newer DSCS III satellites such as solid state amplifiers, but changes have been very limited. The DSCS III satellite is based on an old desic and uses out-of-date technology. In addition, more and more mobile users are demanding DSCS resources, changing the original DSCS mission from supporting fixed users to supporting both fixed and mobile users. In order to meet the growing demand for high capacity communications in the future, especially for small mobile users such as the Navy, a new up-to-date DSCS Follow-On (DSCS F/O) satellite needs to be developed.

Two options for a DSCS F/O are proposed. The first option for a new DSCS satellite is to merge new technology used in the commercial satellite sector into the DSCS design. Several improvements and additions to the original DSCS design should include:

- Additional Multibeam Antennas (MBAs) for tactical users
- Additional Gimballed Dish Antennas (GDAs) capable of receiving and transmitting a higher gain spot beam for mobile users
- High power phased array antennas to increase transmit and receive gain
- Modern high power Solid State Amplifiers and 160 watt TWTAs (Cook, 1994)

- Improved lightweight ferrite multiple Beam Forming Networks (BFNs) in uplink and downlink MBAs to generate independent beams to support widely dispersed tactical users such as the Navy
- Additional channels to support more users
- Improved Low Noise Amplifiers (LNAs) to increase transmit and receive gain
- Common bus architectures which will allow quick assembly and redesign
- Frequency reuse which allows spatially diverse global terminals to share common channel frequencies thereby making bandwidth use more efficient
- C-band or Ka-band transponders in addition to X-band
- Implementation of a Direct Broadcast Satellite (DBS) service package into the communications payload allowing broadcast of weather, training, intelligence, and other multi-user information.

These improvements and additions will provide low to medium protected circuits and high capacity unprotected circuits to both mobile and fixed users in the future.

A second option for the DSCS F/O satellite is to supplement the current DSCS III constellation with modified commercial systems. The commercial satellite supplements will be modified to operate in the military X-band frequency and will provide high capacity unprotected service to mobile and fixed users. The commercial satellites will take full advantage of modern new technology and can even be tailored to provide broadcast service. The DSCS III satellites will continue to provide low capacity protected circuits and selected high capacity unprotected circuits to mobile and

fixed users. This option will allow the Department of Defense to maintain control of satellite resources for military use. In addition, the DSCS III will not have to be redesigned.

It is also recommended that the Navy continue using INMARSAT and INTELSAT for high capacity communications and surge capability until more bandwidth and power can be freed up on the DSCS network or an improved DSCS F/O is launched into orbit. INMARSAT and INTELSAT should serve as surge communication mediums in the future.

There are several recommendations on how best to use these commercial systems in the future. First, C-band transponders and earth coverage antennas offer the most significant advantage to the Navy. Ku-band transponders with steerable antennas are too susceptible to rain attenuation, and they degrade security of the fleet. Second, the Navy needs to coordinate dedicated transponders or channels with INMARSAT and INTELSAT for future regional conflicts. The military should not have to pay exorbitant costs for quickly needed bandwidth as it did during Operation Desert Shield/Storm. Third, the Navy needs to coordinate with INTELSAT for better ocean coverage in the future. The Navy should take every opportunity now to secure global transponders on future INTELSAT VII and VIIA satellites. Finally, Host Nation Agreements need to be established as soon as possible. The military cannot afford to wait three months to two years once a regional conflict develops.

A final recommendation concerns the use of DSCS, INMARSAT, and INTELSAT antennas. Naval ships were not designed for large, satellite tracking, parabolic antennas. The antennas are too large and bulky to place at the top of the ship's mast. Therefore, the antennas have to be installed on lower height platforms on most Naval vessels. This type of installation causes satellite communications to be blocked for a small portion of the time during operation. On vessels where this blockage occurs, dual antennas must be mounted to ensure constant, reliable satellite communications. Short of redesigning entire ship superstructures, dual antennas appear to be the only current viable solution to mast blockage. In addition, in order to maximize the use of the allocated portion of each DSCS transponder, seven foot diameter X-band SHF antennas must replace four foot diameter antennas as soon as possible.

APPENDIX. ACTIVE INTELSAT COMMUNICATION CAPABILITIES

TABLE X. INTELSAT V COMMUNICATIONS CAPABILITIES (Martin, 1991, p. 56-60)

	INTELSAT V
KU-Band:	
Transponders	6
Uplink Frequencies	14.004-14.498 GHz
Downlink Frequencies	10.954-11.191 GHz 11.459-11.698 GHz
Bandwidths	72-241 MHz
TWTAs	Five 10 Watt TWTAs
Antennas	Two steerable beam reflectors
C-Band:	
Transponders	21
Uplink Frequencies	5929-6423 MHz
Downlink Frequencies	3704-4198 MHz
Bandwidths	36-77 MHz
TWTAs	Eight 8.5 Watt TWTAs Three 4.5 Watt TWTAs
Antennas	One transmit earth coverage horn One receive earth coverage horn Two reflectors
Total Capacity	12,000 two-way voice circuits Two TV circuits

TABLE XI. INTELSAT VA COMMUNICATIONS CAPABILITIES (Martin, 1991, p. 61-63)

	INTELSAT VA
KU-Band:	
Transponders	6
Uplink Frequencies	14.004-14.498 GHz
Downlink Frequencies	10.954-11.191 GHz 11.459-11.698 GHz or optional 11.7-11.95 GHz 12.5-12.75 GHz
Bandwidths	72-241 MHz
TWTAs	Five 10 Watt TWTAs
Antennas	Two steerable beam reflectors
C-Band:	
Transponders	26
Uplink Frequencies	5929-6423 MHz
Downlink Frequencies	3704-4198 MHz
Bandwidths	36-77 MHz
TWTAs	Ten 8.5 Watt TWTAs Three 4.5 Watt TWTAs
Antennas	One transmit earth coverage horn One receive earth coverage horn Two reflectors
Total Capacity	15,000 two-way voice circuits Two TV circuits

TABLE XII. INTELSAT VI COMMUNICATIONS CAPABILITIES (Martin, 1991, p. 65-69)

	INTELSAT VI
KU-Band:	
Transponders	10
Uplink Frequencies	14.004-14.498 GHz
Downlink Frequencies	10.954-11.191 GHz 11.459-11.698 GHz
Bandwidths	72-159 MHz
TWTAs	Four 8.5 Watt TWTAs
Antennas	Two steerable beam reflectors
C-Band:	
Transponders	38
Uplink Frequencies	5854-6423 MHz
Downlink Frequencies	3629-4198 MHz
Bandwidths	36-72 MHz
TWTAs	Two 40 Watt TWTAs Eight 20 Watt TWTAs Three 16 Watt TWTAs Two 5.5 Watt TWTAs Two 2 Watt Field Effect Transistor Amplifiers (FETAs)
Antennas	One transmit earth coverage horn One receive earth coverage horn Two reflectors
Total Capacity	24,000 two-way voice circuits Three TV circuits

TABLE XIII. INTELSAT K COMMUNICATIONS CAPABILITIES (Martin, 1991, p. 74-75)

	INTELSAT K
KU-Band:	
Transponders	16
Uplink Frequencies	14.004-14.498 GHz
Downlink Frequencies	11.45-11.95 GHz (N/S America) 11.45-11.7 GHz 12.5-12.75 GHz (Europe)
Bandwidths	54 MHz
TWTAs	Twenty-Two 62.5 Watt TWTAs
Antenna	Two reflectors
C-Band:	None
Total Capacity	65,000 two-way voice circuits using digital circuit multiplication 32 TV circuits

TABLE XIV. INTELSAT VII COMMUNICATIONS CAPABILITIES (Martin, 1991, p. 77-81)

	INTELSAT VII
KU-Band:	
Transponders	12 Uplink Channels 10 Downlink Channel
Uplink Frequencies	14.004-14.498 GHz
Downlink Frequencies	10.954-11.191 GHz 11.459-11.698 GHz 11.704-11.941 GHz 12.504-12.741 GHz
Bandwidths	34-112 MHz
TWTAs	Eight 50 Watt TWTAs Seven 35 Watt TWTAs
Antennas	Three circular parabolic reflectors
C-Band:	
Transponders	30 Uplink Channels 26 Downlink Channel
Uplink Frequencies	5929-6423 MHz
Downlink Frequencies	3704-4198 MHz
Bandwidths	34-77 MHz
Solid State Amplifiers (SSAs) - replaces TWTAs	Three 30 Watt Seven 30/20 Watt Six 16 Watt Seven 16/10 Watt
Antennas	One transmit earth coverage horn One receive earth coverage horn Three reflectors
Total Capacity	18,000 two-way voice circuits Three TV circuits

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